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ABSTRACT

This publication is designed for educators, researchers, and students in both school and university audiences. In an effort to give a more in-depth analysis of the Inquiry Type Science Curricula, this publication defines its terms, describes goals and objectives of modern science curricula, gives a history of, reasons for, and description of present learning theories and their impact on inquiry. This document also examines the various roles of the teacher who implements inquiry methods in science and also attempts to determine the thought processes used during an investigation by the student. The publication also includes a summary and recommendations chapter. This document could be useful to those students or educators seeking a clearer understanding of inquiry learning at any level. (MR)

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Number 6

THOUGHT PROCESS ANALYSIS

An Aid for Understanding
Inquiry-Type
Science Curricula

by

William E. Searles

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CHAPTER I

INTRODUCTION

Schools today must prepare children for a rapidly changing society. The inquiry method of teaching and learning, in which the student learns how to learn, is considered to be the most appropriate method to achieve this goal.

Considerable resources have been applied to the production of inquiry-type curricula. Unfortunately there has been considerable looseness in the usage of terminology associated with the inquiry method. Different operational definitions were developed by curriculum designers working within the structural organization of various disciplines. A further weakness may be seen in the fact that there is no adequate theory to describe or explain the exact meaning of inquiry-type curricula. It is this lack of theory which prevents the formulation of an acceptable definition of the inquiry method and thereby creates problems for the educator, particularly in the application of the method in the classroom.

Little aid for understanding inquiry is to be gleaned from research. In 1965, Wittrock considered that "the current state of research on discovery is very disappointing and precludes any important conclusions about teaching or learning (Wittrock, 1966, p. 45)." The nature of research on the inquiry method has seemingly not changed, for recently, according to Tanner (1971), "many difficulties stem from inadequacies in experimental design and the use of improper criterion measures (p. 129)." Whiist

many claims have been made for the success of the inquiry method there are no validated research findings to substantiate them.

Purpose

Before an educator adopts a curriculum there is a serious need for careful evaluation of its suitability for the particular educational environment. The purpose of this monograph is to answer this question: To what extent can a thought process analysis of a laboratory investigation in an inquiry-type curriculum aid the educator in evaluating the suitability of a curriculum? Other questions inherent in this problem are: What is inquiry? Can inquiry be taught? Can inquiry-type curricula be evaluated? There is a need for the educator to understand the crucial facets of an inquiry-type curricula, for, whenever the concept of inquiry is vague, or ambiguous within a particular setting, it will impede the educator's matching of subject material with the learner, and the educational environment.

The concern shown for the student's thinking in this monograph emanates from the fact that the development of a student's thinking ability has been an important objective in education for many years. Also, it is the student's ability to formulate his own thoughts that is the criterion for the success of an inquiry-type curriculum. Thinking becomes a critical problem in curriculum where careful planning of sequences in the development of thought is so important, for according to Taba (1962),

A sequential development is possible only if there is a clear understanding of both the specific behaviors that compose thinking and of the necessary steps in their development (p. 220).

It seems unfortunate, then, that the "one basic reason why better results are not achieved is that the majority of teachers have no knowledge of the thinking process (Burton, Kimball, & Wire, 1960, p.VI)."

The recognition of the thought processes inherent in a curriculum is crucial to a meaningful curriculum evaluation for learning occurs within the individual, and thinking is basic to this activity. Dewey (1933) was most concerned with the importance of this and stated,

It is evident that education is primarily concerned with thinking as it actually takes place in individual human beings. It is concerned to create attitudes favorable to effective thought, and it has to select and arrange subject matter so as to promote these attitudes (p. 73).

Now providing that the educator can obtain an outline of the student's thinking as he works through an inquiry activity, it should provide him with a base for understanding the method being used, and the preparation of a suitable educational environment. Specifically, a thought process analysis may aid the educator by revealing thought processes and thought patterns which will

1. provide criteria on which curriculum planning can be based,
2. aid curriculum specialists in constructing logical learning sequences,
3. indicate instructional conditions necessary for concept development,
4. establish commonalities within a curriculum and related curricula, and
5. influence the development of very specific frames of reference for evaluation procedures.

The recognition of thought processes and thought patterns requires an understanding of related educational theory in the information acquired is to be of any value to the educator. In this respect the following important underpinnings of inquiry-type science curricula will be examined prior to the analysis.

The goals and objectives of science education are in a constant state of flux to accommodate the demands of society in this rapidly changing world. However, there is one major goal which influences all others and that "is to develop scientifically literate and personally concerned individuals with a high competence for rational thought and action (National Science Teachers Association, 1971)." It should prove useful for an understanding of the objectives to reflect upon the implications of this major goal of The National Science Teachers' Association (also see Appendix A).

The purpose of the brief historical survey of inquiry is to provide a context in which current practices concerning this method can be viewed in their true perspective. Over the years, many scholars have supported the basic principles of inquiry and in recent years eminent psychologists have substantiated its usefulness in education. The widespread use of inquiry in most of the disciplines, and with all age groups, has created some confusion as to its exact meaning. Two basic types of inquiry and their associated investigative processes will be examined and related to models to explain characteristics of the method.

There are many instructional techniques, and some students may learn better from one method than from another. The pedagogical

principles used with inquiry methods require special consideration. Not only must the presentation be organized for the processing of content, but also to those important aspects of the curriculum, the learner, and the investigative environment. It is here, then, where knowledge is communicated to the learner, that a thought process analysis of the student's thinking should prove to be most useful.

Method of Analysis

A major assumption of this monograph is that a student's written laboratory report is a true reflection of some of the thoughts generated as he progressed through an investigation. Further, it is assumed that a student's thought processes can be classified, as are educational objectives.

The technique employed in the analysis is the recognition (identification) of the processes of science used by the student during the inquiry and verbalized in the report. The recorded thought process is then placed into one of the following categories:

1. Comprehending Knowledge,
2. Application of Knowledge,
3. Analysis, Synthesis, and Evaluation of Knowledge.

The analysis of the laboratory report continues until an outline of all the processes of science used by the student have been identified and classified. In this manner, the student's thinking within an inquiry may be established and related to the curriculum.

It should be recognized that the term used for each of these processes of science is in a technical language, the meaning of which is described in the following. These definitions are derived from The World Book Dictionary, Chicago: Field Enterprises Educational Corporation, 1970.)

Definition of Terms

Assuming:	To take for granted without actual proof.
Classifying:	To arrange or distribute in classes according to some method, or system.
Comparing:	To point out the similarities and differences of.
Conceptualizing:	An idea generalized from particular and relevant experiences.
Discovering:	To find something not known before.
Discriminating:	Observing and noting a difference.
Estimating:	Forming a judgement or opinion about (how much, how many, how good).
Explaining:	To make plain or clear, to give reasons for, account for.
Extrapolating:	The act of calculating and extending beyond a known term or series of terms.
Generalizing:	The process of making one general statement to represent a broad or general type of form, class, law, or function.
Hypothesizing:	Making an assumption, prediction, or educated guess because it seems likely to be a true explanation of what did, or may happen.
Illustrating:	To make clear or explain by example, pictures, diagrams, charts, symbols, etc.
Imagining:	The process of forming a mental image or picture in one's mind.
Inferring:	The mental process of reasoning and trying to explain an observed fact.

Inquiring:	The process of investigating a problem in search of information or knowledge by examining the facts or principles. The pattern of the inquiry is dependent on the type of investigation and the reasoning of the individual. Intuitive thought may occur during the inquiry.
Interpreting:	The act of explaining the meaning of.
Inventing:	The mental process of devising something new.
Investigation:	A thorough search and gathering of information which is then carefully examined.
Judging:	To form an opinion, make an estimate of, weigh the facts carefully in arriving at a decision.
Justifying:	To give a satisfactory reason for something which has occurred.
Observing:	The process of perceiving phenomena using the senses and making a mental note of.
Predicting:	To forecast the result beforehand.
Problem Solving:	Refers to all those mental and experimental activities a person goes through in attempting to resolve an incongruity.
Processes: (Reflective or Critical Thinking)	The cognitive abilities the mind is capable of performing such as observing, classifying, comparing, etc., associated with inquiry and decision making.
Rearranging:	The process of placing an item or fact in a new or different way.
Relating:	To connect in thought or meaning as when the many different types of cells in the human body are related to the whole.
Structuring Knowledge:	The relationship of concepts to each other in a hierarchy of ideas that proceed from the simple to the more complex.
Summarizing:	The giving of a brief account or statement which includes the main points of the matter being considered.

Theorizing: A generalization or body of related principles that explains observations or ways of solving problems, for example, learning theories and evolution.

There are many possible outcomes of a thought process analysis and the concerned educator will undoubtedly look for those which will help him to improve those aspects of the curriculum for which he is responsible. The teacher will search for those factors which will help him construct meaningful objectives that will aid him in developing a sound instructional program. For, of all the teacher's "responsibilities one looms overwhelmingly more important than the others; that one responsibility is to change the behavior of his students (Peterson, 1969, p. 13)." All modern science curricula have recognized this important aspect and have stressed the use of objectives. To the extent that a thought process analysis can help a teacher formulate objectives it becomes a useful tool.

CHAPTER II

GOALS AND OBJECTIVES OF MODERN SCIENCE CURRICULA

This chapter is devoted to showing the reader the importance of objectives in modern science curricula. The nature of science will be examined initially for it is implicit to, and maintains a controlling influence over, all science curricula. The position of the National Science Teachers Association on scientific literacy will be considered prior to examining the objectives related to the elementary and high school science programs.

The Nature of Science

The complexity of the nature of science has caused many scientists to refrain from making a definition of science, and instead, to merely list a number of its characteristics. To appreciate the objectives of science and science teaching it is necessary to recognize and understand that there are two distinct areas in science:

- (a) the accumulated body of knowledge with its structural organization, and,
- (b) the refinement and verification of this knowledge by constant investigation and experimentation using the methods of science.

In this respect, (a) is considered to be the static area of science which is bound together by principles, laws, and theories into an organized body of information. Within this context of science are found the facts which are used to explain environmental phenomena. These facts are also known as the concepts of science which fit into a pattern of knowledge referred to as a conceptual scheme. As discoveries are

made, and new information replaces the old, changes occur in the structure of science. The dynamic nature of science is represented in (b) which subjects the present state of knowledge to a continuous self-correcting inquiry process. Science is both a process and a product of that process.

In order to understand science the student must appreciate how the knowledge was obtained, the strength of its foundations, and how it fits into the conceptual framework. To achieve this end, the curriculum worker must design a curriculum in which both areas of science are in accord with this dual nature.

The particular science curriculum objectives referred to in this monograph are those acknowledged to be representative of modern science curricula. These objectives are in agreement with the requirements of the inquiry-type method and of the nature of science. It should also be recognized that implicit in these objectives is the need to develop scientifically literate individuals whom Collette (1973) considers should be able to

identify that which is known for certain, that which is supported by strong evidence, and that which is merely speculative; he should also be conscious of the ever changing nature of science (p. 4).

The objectives attempt to present a true picture of science so that students will recognize the dynamic nature of life and the environment, develop a positive attitude towards change, and be prepared for the future.

The National Science Teachers Association (1971) based its goals on the belief that achieving scientific literacy involves the

development of attitudes, process skills, and concepts, necessary to meet the more general goals of all education, such as:

- . learning how to learn, how to attack new problems, how to acquire new knowledge.
- . using rational processes.
- . building competence in basic skills.
- . developing intellectual and vocational competence.
- . exploring values in new experiences.
- . understanding concepts and generalizations.
- . learning to live harmoniously within the biosphere (pp. 100-101).

In short, the intent was to promote the development of man as a rational human being by implementing objectives to achieve these goals.

Modern science curricula use a variety of educational objectives to achieve their goals:

1. General objectives related to the overall ends of the curriculum, an example of which is to be found later in this chapter -- dealing with the Science Curriculum Improvement Study--SCIS.
2. Specific objectives relating to means and particular fragments of knowledge were stated in the teachers' guide for a particular curriculum, e.g., The Biological Science Curriculum Study (Peterson, 1969) presented a number of these objectives to illustrate their usefulness.
3. Lists of behavioral objectives are found in the most recent science curricula and include a wide array of behaviors that are applicable to inquiry-type activities. Examples of these are to be found in Teaching Science as Continuous Inquiry (Rowe, 1973, pp. 5,43,77,99,131), and The Biology Teachers' Handbook (Klinckman, 1970, pp. 27-43). At this stage it should prove advantageous to examine the setting in which these objectives are found.

Many interesting examples of the first two types of objective are found in the Elementary School Science Curriculum prepared by the American Association for the Advancement of Science (1967) known as Science--A Process Approach (pp. 1-15). This curriculum had the benefit of the findings and advice of several eminent psychologists and scientists. It focuses upon ways of developing basic skills in the processes of science by emphasis on the laboratory method of instruction. It attempts to deal realistically with the development of intellectual skills. Two of these examples of the objectives are that students

1. Will apply a scientific mode of thought to a wide range of problems, including social ones, distinguishing facts from conjectures and inferences, and identifying the procedures required to obtain verification of hypothesis and suggested solutions.
2. Will acquire an understanding of the structure of those particular scientific disciplines he pursues in junior and senior high school more rapidly and with less difficulty than is the case with students today.

As can be seen, these objectives are general to the point that they refer to a wide range of problems, including social ones, and an understanding of the structures of disciplines. They are of such a general nature that the teacher can interpret them according to the needs of the students.

Other of these objectives were concerned with the interpretation of scientific communications, the identification of a question being investigated, and the processes inherent in a scientific experiment. From the experience gained in these experiments it is hoped that students can design and conduct scientific investigations which will thereby create an interest in scientific activities during

their leisure-time pursuits.

The specific objectives of the AAAS curriculum are related to the processes of science. Both content and process are developed sequentially within a hierarchical organization of activities. In the primary grades eight processes have been identified as objectives which continue throughout the program.

- They are:
1. Observing,
 2. Classifying,
 3. Measuring,
 4. Communicating,
 5. Inferring,
 6. Predicting,
 7. Recognizing Space/Time Relationships,
 8. Recognizing Number Relationships.

As the program develops it becomes increasingly interrelated with corresponding development of other processes. These are rooted in the simple processes and are considered appropriate for acquiring a scientific approach to knowledge at the intermediate grade levels.

The Integrated Processes are:

1. formulating hypotheses,
2. making operational definitions,
3. controlling and manipulating variables,
4. experimenting,
5. interpreting data, and
6. formulating models.

This reference to processes dominates the entire curriculum. In fact, "the AAAS stresses the child's practice with the processes and uses the phenomena only as vehicles and the concepts as tools (Karplus and Thier, 1967, p. 8)". The title of this curriculum, Science--A Process Approach, is thus a valid one.

The AAAS curriculum was merely one of the many interesting science curricula which arose from the Curriculum Reform Movement of the 1960s. The Science Curriculum Improvement Study, known as SCIS, proved to be another. "The SCIS stresses the concepts and phenomena, with process learnings an implicit by-product of the children's experimentation, discussion, and analyses (Karplus and Thier, 1967, p. 8)." The designers of the SCIS curriculum considered that "the conceptual structures creates a context for the new experiences that enables it to be assimilated rationally in relation to other experiences (p. 6)." The objective central to this inquiry-type program reflects the following belief:

The teaching objective is to give the students sufficient knowledge and experience so that they will be able to have some understanding of the scientific work being carried out by others, have a functional understanding of science concepts, and have an inquiring open mind. These qualities have been called 'scientific literacy (p. 30).'

The SCIS program attempts to achieve this objective as follows:

1. By involving children in science learning experiences where they do experiments, make observations and draw conclusions.
2. By making the experiences different from those children are usually exposed to in their homes and school environment.
3. By making the experiences direct ones and not read in a book.

4. By supplying substantial guidance and discussion and by making an effort to relate the unusual experience to the students own familiar experience (pp. 4-6).

The inquiry-type science curricula introduced into the high schools was directly related to disciplines such as physics, chemistry, and biology. Of these programs, the Biological Science Curriculum Study - BSCS is considered to be the most successful, if one is to judge by the number of countries throughout the world which have adopted it (Hurd, 1969). Funded by the National Science Foundation of the United States, thousands of college, university, and high school educators planned and developed the classroom materials between 1959 and 1968. The BSCS recognized that regardless of the excellence of any curriculum, the most important link in the chain is at the teacher-student interface. To this end, by extensive cooperation, the BSCS Teacher Preparation Committee issued a special publication No.6, known as New Materials and Techniques (Peterson, 1969, pp. 13-18), and a second edition of the BSCS--Biology Teachers' Handbook, edited by Evelyn Klinckman (1970, pp. 25-43). Both publications included a variety of objectives and teaching strategies to be used to elicit classroom behaviors associated with the BSCS objectives.

The BSCS required a strong dedication by the teacher to the work he undertook. To this end, and the "Commitment Required for the Effective Teaching of Modern Biology" was developed. It stated that:

the successful teacher of modern biology must willingly be committed to:

1. teaching a biology course in which the content and procedures relate to appropriate overall conceptual themes,
2. teaching a biology course based on stated and specific objectives,

3. teaching biology as a laboratory-centered course,
4. student inquiry as the important part of teaching biology,
5. the student's mind as the most important factor in learning by inquiry (Peterson, 1969, pp. 11-12).

The objectives of this commitment continued in a similar vein until twenty in all were covered.

The content, themes, and objectives of BSCS were carefully delineated with clear explanations of the ideas inherent in each topic. Seven levels of biological organization were outlined, as can be seen in the following four examples:

1. The Molecular Level simple sugars, etc.,
2. The Cellular Level mitosis, etc.,
3. Organ and Tissue blood circulation, etc., and
4. The Organism as an Individual . . . behavior patterns, etc.

At each level a brief description is given with reference to accumulated knowledge and associated functions.

Nine unifying themes were selected to bind together the various materials included in BSCS. These emanated from two very important considerations, the content and structure (processes) of modern biology, and the needs and problems of students. The following order and arrangement of these themes suggest their inter-connections: 1-5 concern content, 8-9 the context of data and inference through which their content is conveyed, and 6-7 are intermediate; they concern both structure (processes) and content.

1. Change of living things through time: evolution
2. Diversity of type and unity of pattern in living things
3. The genetic continuity of life
4. The complementarity of organism and environment
5. The biological roots of behavior
6. The complementarity of structure and function
7. Regulation and homeostasis: preservation of life in the face of change
8. Science as enquiry
9. The history of biological conceptions (Klinckman, 1970, p. 14).

These thematic goals of BSCS were developed with the recognition that they would be enlarged upon by individual teachers. Nevertheless, the following was drawn up as a guide:

To achieve the general objectives of the BSCS themes, the student should demonstrate some or all of the following behaviors in the context of the theme in question:

1. Observe and record data.
2. Measure within specific limitations (imposed by the teacher, problem, etc.).
3. Communicate his data to other students and the teacher.
4. Operate various pieces of scientific equipment.
5. Interpret graphs and other forms of data.
6. Identify relationships.
7. Formulate hypotheses.
8. Design experiments.
9. Identify cause and effect relationships.
10. Identify causative and contributing agents.
11. Generalize and formulate tentative conclusions based on relevant data (Peterson, 1969, p. 16).

At this level of stating objectives the BSCS saw fit to state that the "most critical aspect of stating an objective is that of clarity (Peterson, 1969, p. 16). In this respect, and in order that the teacher may effectively communicate his intentions to the student, the essential requirements of a behavioral objective were stated.

Summary

In this chapter a distinction was made between the dynamic and the static nature of science. To provide a balanced view of the scientific enterprise it is necessary for the educator to develop learning activities relevant to both of these areas in the science curriculum and, in doing so, maintain the academic integrity of the discipline.

A meaning for scientific literacy was presented followed by some beliefs for achieving it. The different types of objectives used by elementary and high school science curricula to achieve this goal were

then outlined. An examination of the objectives reveals concern not only for specific science content, but that what is taught should resemble what scientists do - the processes used in scientific inquiry. The objectives which involve a process of science show concern for human intellectual development inasmuch that they refer to the ways of processing information used by students during an inquiry.

CHAPTER III

INQUIRY IN SCIENCE EDUCATION

The purpose of this chapter is to examine the role of inquiry in modern science curricula. Consideration will be given to the following dimensions: the history of inquiry, the semantic problem, modern definitions of inquiry, reasons for inquiry in science instruction, two types of inquiry and models for the understanding of them, models developed by learning theorists, and the arguments for and against the use of inquiry.

The first section will show the development of inquiry as a method used by man to investigate his environment. Throughout history, a variety of terms have been used to describe this method, and these terms will be used in this monograph to illustrate the need for the use of precise terminology for the sake of clarity and understanding. The second section considers the problematic situation that has arisen from the loose usage of poorly defined terms and of particular perceptions of the inquiry method. Four recent definitions of inquiry and the implications of each in science education are examined in the third section. The reasons for using inquiry in science instruction are considered in the fourth section prior to examining the two types of inquiry proposed by Schwab in section five. Models are used to illustrate the problem of explaining the student's activities during an inquiry. The pedagogical strategies associated with the models are then outlined to provide an understanding of inquiry. Section six outlines three different models

developed by learning theorists to illustrate particular points of view regarding instruction and inquiry. The final section examines arguments that are for or against the use of inquiry.

A History of Inquiry

Man's inquiring ways allowed him to recognize and to solve problems as he progressed from primitive beginnings to the modern era. Socrates (469-399 B.C.) is closely associated with inquiry. He believed that man's nature leads him to act correctly and in agreement with knowledge, that the correct method of discovering the common characteristics was by inductive means. As a teacher he engaged his listeners in a series of verbal interchanges by using a method of questioning assumptions that allowed men to proceed from less adequate to more adequate definitions. By his astute questioning technique Socrates subjected his students to rigorous self-examination, and in so doing helped them discover their own solutions to problems. This process became known as the Socratic Method (Saunders, 1970).

Aristotle (384-322 B.C.) extended the Socratic inquiry model. He is considered to be "the first philosopher to analyze the process whereby certain propositions can be logically inferred to be true from the fact that certain other propositions are true (Soll, 1970, pp. 629-630)." Aristotle developed a set of principles governing the collection of facts and the ensuing analysis. The techniques and principles used in determining logical proof are generally referred to as 'Aristotelian logic' and are still used in scientific inquiry today.

The Holy Bible contains many illustrations of man's inquiry during biblical times. One example can be seen in the book of Matthew when Jesus is reported to have said, "seek and you shall find (Matthew, VII, 7)" in other words, you shall be rewarded by your inquiry.

Abelard (1079-1142), the French philosopher and churchman, developed a formula to help his students solve theological problems of a contradictory nature. The formula was to

1. state the problem,
2. locate and expose contradictions,
3. form new judgements and real meanings,
4. check the (problem causing) text to see whether there are later retractions of the passage,
5. search for facts to support the statements made,
6. arrive at a conclusion that (a) there is a mysterious reason for the problem to exist and that it is not meant to be solved, or (b) develop a new theory (Compagné, 1893, p. 17).

This sequentially structured activity to solve a problem may possibly be the first example of "the method" to be used to achieve an objective.

In recent history, one of the earliest appeals to teach science as an inquiry can be found in the works of Rousseau (1721-1778). In Emile (1762), he was concerned with the kind of education he thought desirable and stated "let him not be taught science, let him discover it (p. 131)". Evidently, a number of eminent citizens of the eighteenth century were either influenced by Rousseau, or were of like mind. According to Newbury (1966), Priestly suggested in 1790, that chemistry should be introduced as an educational subject and the teaching methods used should be based on investigation so that learners discovered the facts themselves. Pestalozzi, (1746-1827), took a similar stance to Rousseau and Priestly, and advocated "that the individuality of the child must be sacred to the

teacher, and that investigation is the best method of learning facts (Newbury, 1966, p. 124)," but it was not until the 1890's when Professor H.E. Armstrong introduced "the heuristic theory into the teaching of Chemistry and Physics in Great Britain (Newbury, p. 124)" that emphasis was given by educators to this method of teaching.

The heuristic method encouraged the student to develop the attitude of the experienced researcher. It trained the student to use his initiative, develop self-reliance, good judgement, and manipulative skills by personal contact with apparatus and materials in a problem solving situation. Students were allowed to discuss their problems with their peers as they would under research conditions. Stress was placed on the need to be good observers, the collection, recording, analysis and use of data. Emphasis was also placed on a balance, not merely for that used to weigh materials, but also with the use of words and phrases. Every lesson should be in the form of an inquiry with the student placed in the position of the original discoverer.

"Armstrong's heuristic methods were occasionally misunderstood (Newbury, p. 125)," particularly in the area dealing with the student's discovery. "The method cannot be applied to the discovery of fundamental laws (Newbury, p. 126)," in fact, Armstrong only wished the student to find the general conditions under which chemical reactions occurred. Other criticisms were that the enthusiasm and personality of the teacher overly influenced the degree to which the inquiry was a success, or failure, there was insufficient time, some of the experimental methods were too dry and tedious, not all students are able to discover all the

relevant facts, or continually act the part of the original discoverer, etc.. Regardless of such criticism, modified forms of the heuristic method became firmly established as one method to be used in the teaching of science, but, not exclusively.

The degree to which the heuristic method was modified depended not only on the personality and background preparation of the teacher, but also on the subject matter to be taught. Within non-expository limits, it is possible for a whole range of instructional methods to be in agreement with the heuristic method, providing the student's element of discovery is present. In effect,

different kinds of discovery lessons are appropriate for achieving different types of objectives, for dealing with different types of subject matter, and for use with children at different levels of cognitive ability (Morine, 1969, p. 25).

The term heuristic was changed to discovery method as the import of the involved reflective thinking for the student's discovery was recognized and given emphasis.

The twentieth-century orchestrator of discovery as method was John Dewey. He was concerned with the step-by-step reflective thinking engaged in by the student during an investigative learning experience. The problem of what was really involved in the discovery method was still present among educators, and in this respect Dewey considered that

No one expects the young to make original discoveries of just the same facts and principles as are embodied in the sciences of nature and man. But it is not unreasonable to expect that learning may take place under such conditions that from the standpoint of the learner there is a genuine discovery (1961, p. 354).

The controversy and ambiguity regarding the use of the term discovery still remains today, according to Collette (1973), Feely (1972), Morine (1969), Shulman (1968), and many others.

The person most closely associated with the discovery method today is Bruner. "His book, The Process of Education, captured the spirit of discovery in the new mathematics and science curricula (Shulman, 1968, p. 34)." Discovery to Bruner is any acquisition of knowledge by the individual through the use of his own mind. The geometrically increasing quantity of knowledge in this age of science and technology generated a critical problem in the area of what knowledge should be transmitted to the student. Much better, it was reasoned, to teach the skills of logical reasoning as used in the methods of science, in order that in later life the students could effectively accommodate those active modes of knowledge. The discovery method, man undertaking an investigation to solve a problem, was considered the most relevant method to be used.

The Problematic Situation

A variety of terms have been used to describe the assortment of complex methodologies used in the discovery-inquiry method. Terms such as heuristic, problem-solving, reflective thinking, scientific thinking, discovery and inquiry, have been associated with learning experiences of an investigative nature. The lack of clarity regarding the specific meaning of these terms may emanate from the dynamic nature of the investigative process. There are two components interacting during this activity; the information processing activity of the human

brain and the nature of the phenomena being investigated. The lack of knowledge as to what actually occurs at the interface of these two components leaves the educator with only a vague concept of the interactive process. A further hindrance to the clarity occurs during the recorded communication of the investigation; the meaning of words change over a period of time. There is little to guide the development of a universally accepted definitive meaning of discovery-inquiry methods as used in education, as there is, for example, in the naming of chemical compounds.

The discovery and inquiry methods of investigation used by students in science education are now considered as synonymous. When a student undertakes an investigation, an inquiry, he is searching for information, knowledge or truth. At the moment he recognizes the information he was, or, as in the case of serendipity, was not seeking, he experiences the act of discovery. In this manner, an inquiry leads to a discovery. The discovery method is an attempt to reach the experience of discovery; the process of inquiry is therefore implicit in the method. The interrelationship of these two terms, inquiry and discovery, is such that they are considered interchangeable. Inasmuch as an inquiry does not always lead to a discovery, the inquiry method is to be preferred.

This simple development and explanation of the term "inquiry method" is far removed from the confusion which exists regarding its application in the classroom. In her study on the inquiry method, Kaufman (1972) examined the literature of eminent educators and found agreement upon inquiry methods in learning, but disagreement in the objectives of inquiry teaching. The problem arose from whether priority should be given

to the "affective" or "cognitive" goals of the inquiry activity. The study found

substantive differences among authors on three general constituents of the inquiry method:

1. the specific roles of teacher and student in the inquiry process;
2. the nature of the subject matter to be inquired into; and
3. the emotional milieu in which inquiry occurs (p. 2 of abstract).

Authors who stress the affective objectives believe that the problems to be solved should emanate from the students, the teacher acts as a resource person, and that the emotional tone of the classroom is critical to the inquiry. Those who consider the cognitive objectives to be the most important hold that the teacher should pose the problem, structure the inquiry activity, and attach less importance to the emotional climate of the classroom.

The dichotomy of beliefs in the objectives of inquiry teaching may have contributed to the confusion but it has also generated considerable thought as to what is meant by the term inquiry method. If one considers the affective and cognitive goals of inquiry teaching to be extreme positions, then it may be postulated that a whole range of objective positions exist between these extremes. The nature of the student's intellectual ability and interests interacting with the environmental influences present in the classroom dictates the pedagogical strategies, type and level of inquiry to be used. Further credence that a variety of inquiry methods exist can be found by examining the numerous techniques and interaction processes used in an inquiry-type educational activity. This suggests that the term "methods of inquiry" may be more appropriate than the inquiry "method."

Depending upon the learner and the material to be learned, the teaching act does affect the learning process, thus the beliefs and objectives used in inquiry teaching are important. There is a need, therefore, to recognize the divergent nature of inquiry methods and the possible effects on the learner. Whilst this monograph is primarily concerned with the inquiry method, and learning, it cannot escape the influence of the teaching component.

Modern Definitions of Inquiry

There is a tendency in science education literature to treat the term inquiry as though it were interchangeable with its use and meanings in non-instructional contexts. This is apparent in many definitions of inquiry provided in the literature. For instance, Anderson and Koutnik (1972) wrote,

Inquiry is a set of activities directed towards solving an open number of related problems in which the student has as his personal focus a productive enterprise leading to increased understanding and application (p. 4).

In a similar vein, when considering behavior in the classroom, Massialas and Zevin (1976) note that

inquiry as we define it, is behavior which is characterized by a careful exploration of alternatives in seeking a solution to a problem (p. 7).

However, Sund and Trowbridge (1976) suggest "Inquiry is a search for knowledge or truth (p. 37)".

Similarly, Suchman (1966) writes, "Inquiry is the pursuit of meaning (p. 178)."

These definitions mask the conditions which demarcate the instructional and non-instructional contexts and thereby adds to the

confusion regarding the notion of inquiry. The first two definitions listed can be associated with student-centred inquiry in the classroom, and as something to be achieved through instruction. Definitions three and four imply an expertise, a notion in which scholarly-centred inquiry is an achieved fact. Meanings associated with these definitions create ambiguities as to the exact context of inquiry in science instruction. For instance, to what extent should a teacher structure a set of learning activities for the student to learn by inquiry, or should he consider the pupil to be capable of working as if he were at the frontier of knowledge, as Bruner (1960, p. 14) suggests?

Implicit in each definition is the fact that inquiry is an intellectual endeavor. The achievement of one objective merely opens up new vistas to be inquired into for an even greater understanding of the phenomena. In this context, inquiry is used to designate an activity of knowledge building. For the student this means learning new knowledge for himself, whereas in scholarly investigation it refers to the activity which occurs at the frontier of knowledge, and is invariably for the benefit of mankind.

A further distinction can now be made between the first and the last two definitions. Definitions three and four denote a specialized expertise found in scholarly research. In this context the inquirer is in command of a large body of knowledge and investigative techniques upon which he grounds his inquiring. In the instructional setting implied in definitions one and two, there is an emphasis on personal experiences in which students learn skills and gather information which will enable them

to act judiciously within their environment.

Reasons for Inquiry in Science Instruction

Science as a process of inquiry evolved from man's inquiring ways which were refined by the development of attitudes and methods which became part of the scientific enterprise. During the curriculum reform movement of the sixties, science teachers were urged to plan experiences conducive to the student learning science by inquiry, and by so doing, generate and maintain the spirit of inquiry in children. It was reasoned that students could only appreciate inquiry by becoming actively involved in it.

The dynamic nature of inquiry controls in turn the nature of the scientific endeavor to a considerable degree. It may be hypothesized that it wields a similar control over the activities of the learner to the extent that by engaging in an inquiry activity the student obtains significant, meaningful, experiential learning, which comes from personal involvement. When learning by inquiry the learner is in the learning event. To be more specific, the following reasons are usually given for using the inquiry method in science education. Learning by inquiry allows the students to 1. develop an attitude conducive to understanding the nature of science and the role of science in his environment, 2. understand that there is still much to be learned in science, 3. recognize the importance and limitations of the techniques used in science, 4. appreciate that "science is a body of knowledge forged slowly and tentatively from raw materials (Klinckman, 1970, p. 23),"

5. recognize the validity of conclusions of science, the manner in which they arise and are tested, and
6. understand that the human mind is the most vital part of the scientific enterprise.

It is claimed that obtaining knowledge for oneself by the use of one's own mind frequently has advantages. Carin and Sund (1964) claim that by using inquiry,

1. Concepts, theories, principles, and content areas can be learned better.
2. Students cannot learn the skills nor grasp the true spirit of science unless they engage in discovery (p. 11)
3. The sheer joy of discovery is justification enough for scientific inquiry (p. 5).

The reasons generally given for the use of inquiry in science involve two areas of concern, either the traditional science curriculum fails to project the true picture of the scientific enterprise, or claims are made for superior learning activities. However, whilst there is agreement regarding the inadequacies, Tanner (1971) states that the "claims have yet to be substantiated by empirical research (p. 35)."

Stable and Fluid Inquiry

Basically, the unifying thread within all inquiries is the seeking of evidence for the solution of a problem. The number of processes of science used during the inquiry is dependant upon the subject matter content, the degree of complexity of the problem, and the intellectual ability of the inquirer. The problem may prove to be an insuperable one, or the inquirer may lack the skills necessary to employ those processes of science required to solve the problem. The educator must weigh all of these aspects of the inquiry prior to deciding on whether the learning

activity should be a stable or fluid one.

Schwab (1964) considers that stable inquiries are short term in the sense that separate problems can be pursued separately and settled in a relatively short time, as for example, during a single or double school period used for an investigation. His schoolbook version of this construct is:

1. The formulation of a problem.
2. The search for data that will suggest possible solutions to this problem.
3. Reformulation of the problem to include these possible solutions.
4. A determination of the data necessary to solve the problem.
5. A plan of experiment that will elicit the data desired.
6. Execution of the experiment and accumulation of the desired data.
7. Interpretation of the data by means of the guiding substantive structures together with previous knowledge possessed by the investigator (pp. 38-39).

Problems of incoherencies and inconsistencies may, and invariably do, arise during stable inquiry in the classroom. Many of the thought-provoking questions raised by the students are in their very nature the essence of the scientific endeavor. Their recognition of disparities in data, the scientific invalidity of a "one-shot" study, the lack of precision in measurement, an apparent weakness in experimental design, suggests the employment of longterm studies as in fluid inquiry.

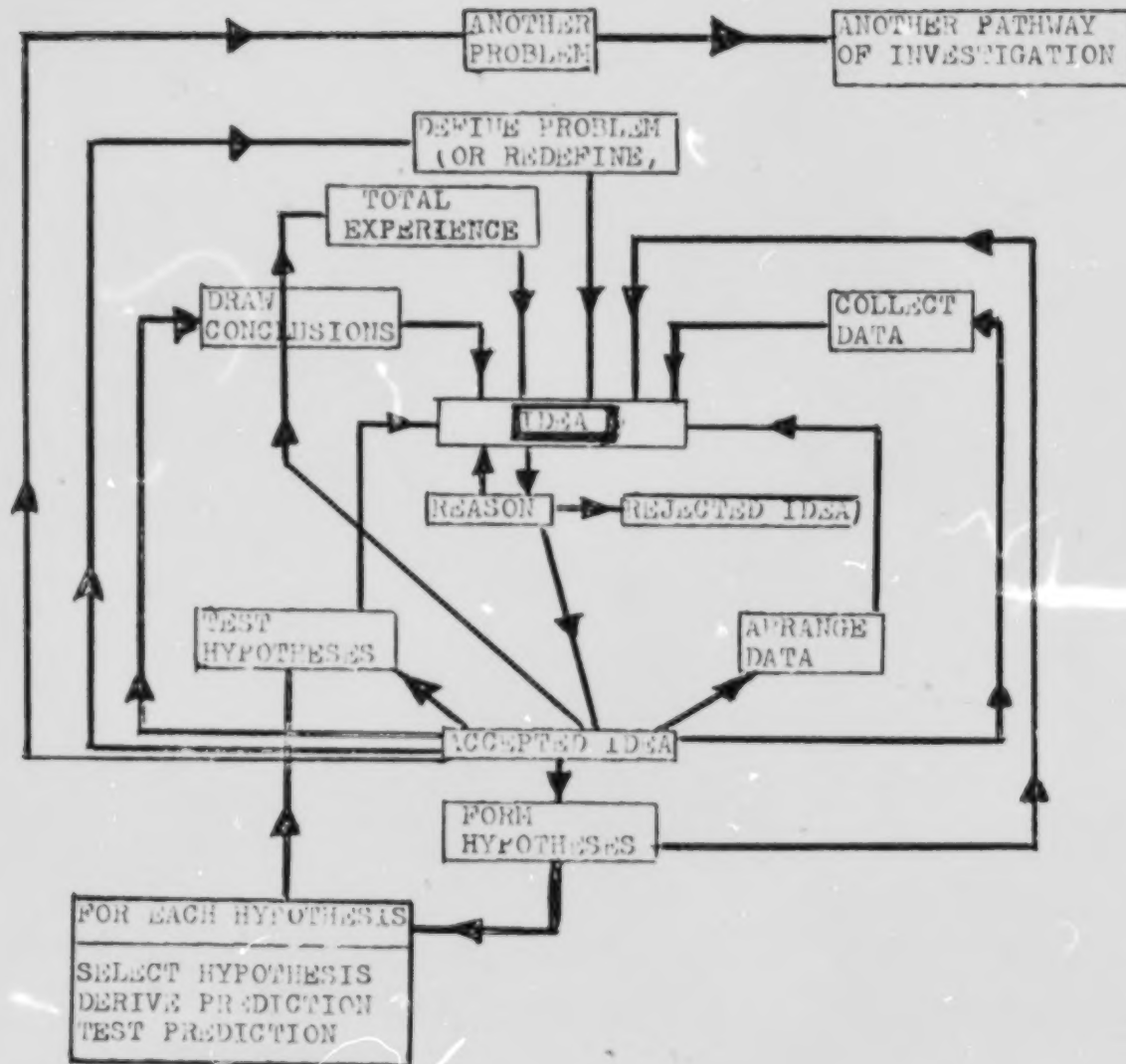
The fluid enquirer has three aims: first, to be alert to the moments of enquiry which reveal inadequacies of principle; second, to obtain such clues as he can from current stable enquiries which will point to the specific weakness or inadequacy that characterizes the principle in question; finally, to devise a modification of the existing structure, or a new structure to replace it, that will embrace more of the richness of the subject matter and take account of the specific weakness discovered in the older principles (p. 41).

Fluid inquiry illustrates the dynamic nature of science in which knowledge becomes redundant or is refined as the principles of science are changed. The flexibility of fluid inquiry appears limitless and is in accord with the definitions of science previously examined. In this sense, inquiry is continuous.

A problem exists in most schools regarding the nature of fluid inquiry. The school's curriculum and its timetable for lessons generally lack the flexibility necessary for students to engage in long-term studies. A further problem exists at the high school level regarding the homogeneity of the students' ability to sustain a lengthy study intellectually, particularly in the formulation of thoughts and the maintenance of interest. The short term stable inquiry is much more conducive to the school's curriculum. It allows the educator to maintain the evolutionary progression of learning activities and thereby present small packages of information amenable to the interests and abilities of the student body. Stable inquiry is favoured by most teachers and is the inquiry method most commonly used.

Stable inquiry provides an easy check on the student's reasoning as they progress through the investigation. The nature of stable inquiry, particularly with reference to time limitations, allows the teacher to keep in contact with a greater number of students as their progress is usually much closer in time than in fluid inquiry. The recognition of the student's process of reasoning permits the educator to apply effective reinforcement when necessary. The interaction of the teacher and the students during an inquiry is extremely important to the success of the

Figure 1

The Process of Inquiry*

* Betty Boyd, Thinking About Inquiry. Toronto: McGraw-Hill Ryerson Ltd., 1972, p.35.

activity. In recent years several authors have attempted to aid the educator in his understanding of inquiry by graphically illustrating the possible pathways of a student's reasoning during an inquiry. Boyd's (1972) "The Process of Inquiry" in Figure 1 provides considerable aid to the understanding of inquiry.

This diagram represents the alternate pathways a student or students may take during an investigation. In Boyd's book it is the outcome of tracing the pathways used by many students during an inquiry. It may be considered that the different pathways used by the students is a reflection of the differences in their intellectual abilities, interests, and previous experiences. Inasmuch that each student's pathway illustrated by Boyd was different, it reveals that "individuals vary in their approach to inquiry (p. 36)."

Body recognizes the complexity of the process of inquiry and considers that her diagram "is still too simple and orderly (p. 34)." For example, the logical reasoning used by a student during problem solving in mathematics can be easily traced as seen in Bloom's Model of Problem-Solving in Appendix B. The student's step by step reasoning is not always apparent for inquiries in other disciplines and this creates difficulties in understanding the process of inquiry. The nature of the learner, the nature of the subject matter being investigated, the investigative processes used, and the nature of the teacher and instructional procedures, are primarily responsible for the complexity.

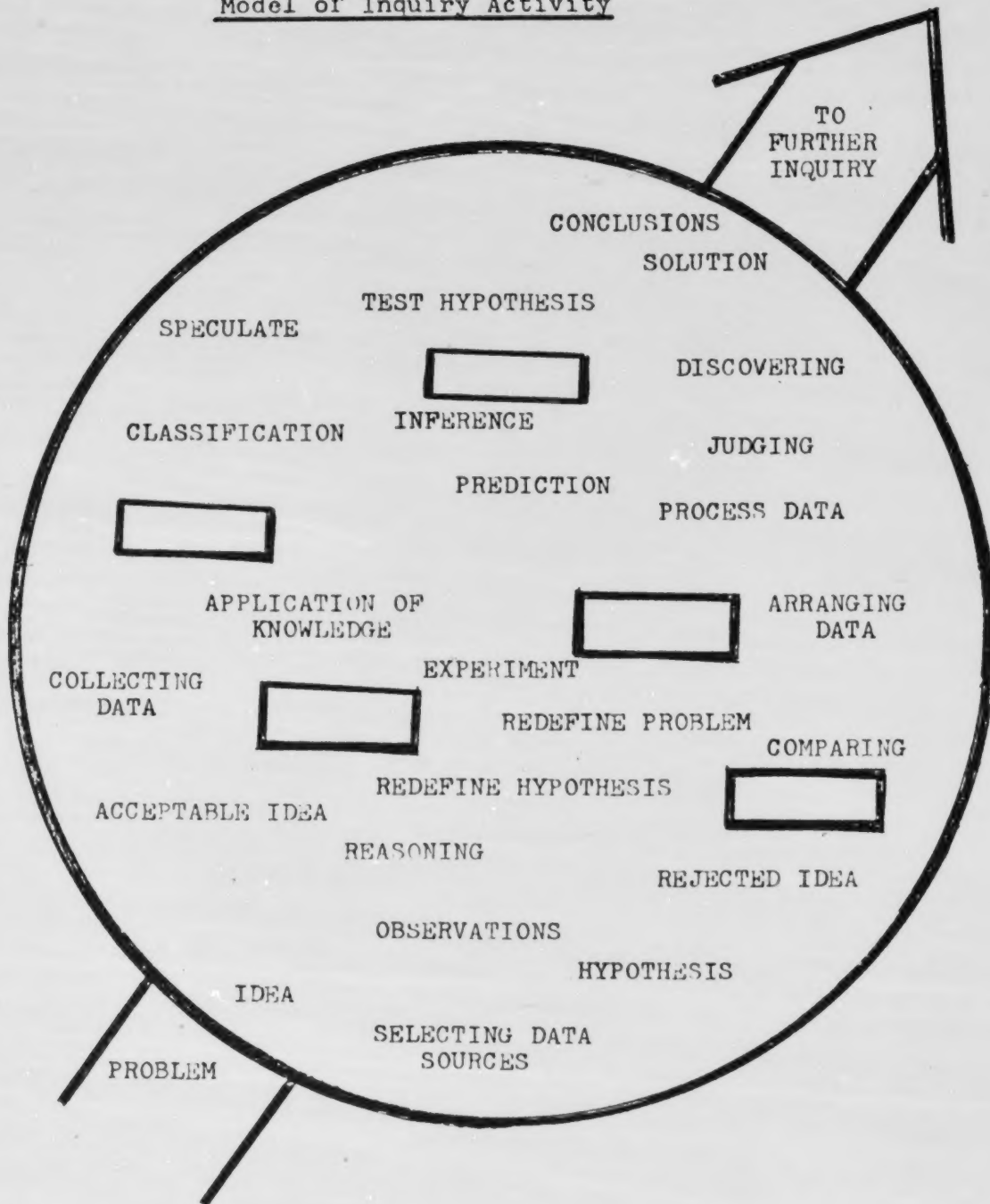
The intricate nature of the process of inquiry may be seen in a scientific inquiry. At the commencement of the activity there may be many false starts, as for instance, when a problem lacks clarity of purpose

and needs to be redefined or reformulated. The direction the inquirer takes during an investigation may prove repeatedly to be unproductive, as if one was lost in a mazelike activity. The student's use of intuitive thought and educated guesses may result in conceptual leaps producing gaps in an apparent illogical pathway. A progressive, logical pathway is often difficult to determine in scientific inquiry.

The Model of Inquiry Activity, Figure 2, was designed to accommodate the difficulty of following a pathway during the process of inquiry. The model may also possibly generate new ideas on inquiry. The investigative processes included in the model are not connected one to another, to avoid even a suggestion of a pathway. This allows for the greatest number of pathways possible towards solving a problem. The enclosed empty spaces within the model represent those processes which may exist in an inquiry, but of which we human beings are not presently aware. There is a progressive stream of processes in this model which culminates in conclusions and the solution of the problem. Thus, whilst the inquirer may be engaged in many kinds of thinking, it must never-the-less be directional if the problem is to be solved cognitively.

Inherent in this model of inquiry activity is the information-processing capability of the student, that is, the processes used by the student to handle stimuli which emanate from the problem and which are encountered during the investigation. Depending upon the nature of the content and the learner, the model generates an educational environment which requires the educator to consider implementing the

Figure 2

Model of Inquiry Activity

following strategies to facilitate inquiry:

1. the implementation of attitudes and processes of science conducive to a scientific enterprise.
2. sufficient time to allow for the successful completion of the investigation,
3. the problem to be solved should create and sustain the interest of the students,
4. a discussion, or type of examination by the class should occur to determine the feasibility of solving the problem,
5. hypotheses are encouraged from the class to guide the student's investigation,
6. proposals for inquiry activities and experimentation are cooperatively examined,
7. students work in small groups and cooperate in the solving of the problem,
8. summaries of group and class data are examined and discussed to test the hypotheses,
9. emphasis is placed on the level of discussion with attention being directed to relevant processes such as assumptions or inferences being made in order to maintain a good scientific attitude,
10. students are responsible for arriving at, and possibly defending their own conclusions,
11. the validity of the conclusions are verified,
12. investigations are related to the overall picture of science,
13. the inquiry is related to the student's environment, and
14. human dignity and thought are prized components of inquiry and are treated accordingly throughout the investigation.

These strategies require considerable planning by the educator if the inquiry is to reach a successful conclusion. The atmosphere associated with this learning activity is one in which the students have the freedom to pursue lines of thought uncluttered by authoritative sources. As may be seen in the strategies numbered four to eleven, a high degree of student responsibility is involved in the inquiry.

The degree of student involvement mentioned on page 26 now warrants a more detailed examination. Of the learning theorists who became interested in the enhancement of inquiry in education, Bruner, Suchman, and Gagné, developed models for use in the classroom. There is a distinct similarity between the instructional methods used by Bruner and Suchman, who favour learning by discovery, whereas Gagné prefers guided learning. Learning by discovery emphasizes maximal participation by the student for learning broad principles in problem-solving activities with minimum teacher guidance. Guided learning stresses the careful sequential development of learning experiences by mastering interrelated basic facts in order to solve a problem. The curriculum worker should understand the different implications of instructional procedures in these models.

Bruner's Learning By Discovery Model

Bruner (1968) considers that the emphasis of instruction should be on the acquisition of knowledge by the student.

We teach a subject, not to produce little living libraries from that subject, but rather to get a student to think mathematically for himself, to consider matters as a historian does, to take part in the knowledge getting. Knowing is a process, not a product (p. 72).

When relating this process to discovery, Bruner (1961) considers the process to be "a matter of rearranging or transforming evidence in such a way that one is enabled to go beyond the evidence so reassembled to additional insights (p. 22)." "Discovery learning usually begins with the presentation of a problem (p. 23)." The student then learns those fundamentals which will enable him to solve the problem. Provocative, or leading questions, are often used Socratically to elicit this discovery. "For Bruner, one starts with the complex and plans to learn the simple components in the context of working with the complex (Shulman, 1968, p. 38)." In this manner, the students'

mastery of fundamental ideas of a field involves not only the grasping of general principles but also the development of an attitude toward learning and inquiry, toward guessing and hunches, toward the possibility of solving problems on one's own (Bruner, 1963, p. 20).

To implement discovery learning in the classroom is to teach the student "to participate in the process that makes possible the establishment of knowledge (Bruner, 1968, p. 72).

Bruner considers that the following techniques are particularly useful for encouraging students to discover on their own:

1. Contrast.
2. The stimulation and use of informed guessing, hypothesis making, conjectural procedures.
3. Participation - particularly by the use of games that incorporate the formal properties of the phenomena for which the game is an analogue.
4. Stimulating self-consciousness (1968, pp. 92-93).

By emphasizing contrasts the problem is clarified so that the students can figure out the problem on their own for, "it is far more interesting to learn the facts after one has tried to figure them out for oneself (p. 95)." Also, when the teacher stimulates self-consciousness about thinking it should help the student recognize the information they used,

how they used it, the connections made, and the strategies used in solving the problem. For Bruner, the emphasis is on the processes used in learning.

Suchman's Inquiry Development Model

Suchman (1966) designed his model "to stimulate and sustain inquiry by the students in the classroom, and to develop their skill in the pursuit of new understanding and meaning through the process of inquiry (p. 7)." He developed problem-focus films and special materials which play a key role in the development of inquiry.

The inquiry session begins with the presentation of a problem using a problem-focus film or demonstration. Invariably the problem involves a discrepant event, that is, an event which is counter to the beliefs of the student. The students raise questions about the event they have witnessed in order to establish what the problem is, and to construct a reasonable theory to account for the discrepant event. "The bulk of the inquiry session is normally devoted to data-gathering questions raised by the students and answered by the teacher (p. 11)."

The inquirer uses questions to obtain information to test and evaluate the constructed theories. All theories are constantly checked by comparison with the gathered data as the inquirer attempts to incorporate it into his theories about the environment. Provocative questions are often used by the teacher to maintain a search for greater meaning. "Focussing and refocussing is a continuous job for the teacher as he attempts to provide maximal stimulus for inquiry (p. 16)."

The teacher must create an environment that invites and supports inquiry. The teacher's role is to;

1. stimulate and challenge students to think,
2. ensure freedom of operation,
3. provide support for inquiry,
4. diagnose the difficulties and help the students overcome them,
5. identify and use the "teachable moments" when new organizers can be effectively introduced (pp. 19-20).

To accomplish this role the teacher should understand the inquiry process, the subject matter being inquired into, what motivates each student, and the psychological processes involved.

Suchman considers the learning involved in his inquiry program "consists of an increase in meaningfulness to the learner. It is a matter of building new structures, new systems, new ways of looking at the world. This kind of learning has its own intrinsic motivation (p.70)."

Gagné's Guided Inquiry Learning

Gagné's (1963) model is derived from a task analysis of the instructional objectives. He is concerned with terminal capability, that is, that which the student is able to do after learning has occurred. To view this capability in its true perspective we must know the "set of conditions which are used to bring about a change in the student's capability (p. 145)," the instructional conditions. To achieve the terminal capability of a scientific inquiry a student would use a set of activities characterized by a problem-solving approach. Each activity used to solve the problem is a prerequisite task one must be able to perform in order to complete the terminal task.

By means of a systematic analysis Gagné identifies separate entities of subordinate knowledge and arranges them in hierarchical fashion as in Figure 3. This hierarchy shows that to complete the terminal task the student must first perform prerequisite task A. In order to perform task A one must also know tasks B, and C, for which there are also a number of prerequisites. Gagné considers that there are two major capabilities which:

represent prior requirements if the practice of inquiry is to be carried out successfully,

1. the capability of generalizing the principles of knowledge to the variety of situations to which they are applicable, and,
2. the capability of discriminating the probable and improbable applicability of hypotheses to new problem situations (p. 147).

Therefore, to be an effective problem solver, the student "must have a knowledge of a great variety of principles which can be potentially applicable to these problems (p. 147)."

Instructions play an important role in inquiry, they should communicate something to the learner which enables him to progress from one point in a learning sequence to a higher level of achievement. According to Gagné (1965) the functions of instructions are to

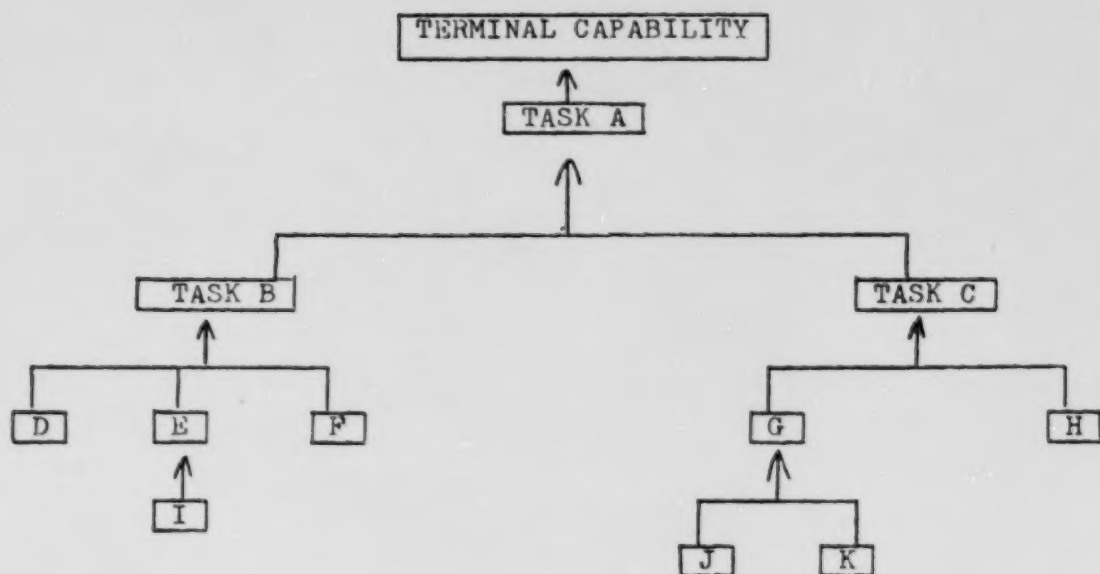
1. make it possible for the learner to identify the required terminal performance . . . ,
2. bring about the proper identifications of the elements of the stimulus situation,
3. establish high recallability of learning sets,
4. provide guidance of thinking (pp. 120-121).

In this sense, instruction should be a considerable aid to the learner.

In Gagné's (1966) guided inquiry the sequential development of the learning activity is from the simple to the complex. He considers

Figure 3

Model of
Hierarchy of Knowledge for Solving a Hypothetical Problem



that transfer of training "occurs because of the occurrence of specific identical (or highly similar) elements within developmental sequences (p. 20)." This has an important bearing on guided discovery where

the subjects are carefully directed down a particular path along which they are called upon to discover regularities and solutions on their own. They are provided with cues in a carefully programmed manner, but the actual statement of the principle or problem situation is left up to them (Shulman, 1968, p. 90).

Gagné's guided discovery is a carefully nurtured movement of the student from the known to the unknown.

Summary of Arguments for Inquiry

The modern curriculum developments found many educators who enthusiastically endorsed the use of inquiry in the classroom and made exaggerated claims for its usefulness. Bruner, and to a somewhat lesser degree Suchman, conducted extensive studies of learning by inquiry prior to stating their arguments for inquiry. From his studies Bruner (1961) has hypothesized that through discovery learning;

1. the learner will become a constructionist by organizing the information he has discovered so that it is more readily viable in problem solving,
2. there will be a tendency for the child to carry out his learning activities with the autonomy of self reward,
3. symbolic modes of representing and transforming the environment arise,
4. the art and technique of inquiry will improve,
5. material is more readily accessible in memory (pp. 21-23).

Bruner (1960) also claims that a student's discovery of regularities of previously unrecognized relations and similarities between ideas results in a self confidence of his abilities, that subject matter becomes more comprehensible, provides adequate transfer of training, and narrows the

gap between elementary and advanced knowledge (pp. 20-28). Also, the understanding of structure which results from discovery enables the student "to increase his effectiveness in dealing intuitively with problems (p. 63)." Suchman's (1966) beliefs are very close to those of Bruner. He considers that learning by inquiry:

1. has its own intrinsic motivation,
2. produces an autonomous student whose inquiry is directed largely by motivation of curiosity,
3. enables the student to build his own conceptual structures that are strong because they grew from his own thinking,
4. places the student at the very centre of the scientific way of life,
5. will help the student grow into a creative adult (pp. 70-78).

The findings of many scholars, including Bigge (1971) and Combs and Snygg (1959) substantiated these arguments with statements which closely resembled the claims of Bruner.

Summary of Criticisms of Inquiry

Much criticism has arisen over the use of inquiry in the classroom. "Knowledge of the psychology of learning has not yet developed to the extent that methods of teaching can be directly extrapolated from that knowledge (Collette, 1973, p. 156)." This may be another reason for the many different interpretations of the term inquiry. The criticisms included here are those of eminent scholars who have held these beliefs for many years.

In his book, The Technology of Teaching, Skinner (1968) levels the following criticisms at the inquiry approach.

1. The method of inquiry is designed to absolve the teacher from a sense of failure by making instruction unnecessary and whilst students can learn without being taught it is no solution to the problem of education.

2. It is impossible for the student to discover for himself any substantial part of the wisdom of his culture and no philosophy of education proposes that he should. Great thinkers build upon the past, they do not waste time re-discovering it.
3. It is dangerous to suggest that it is beneath the dignity of the student to memorize facts, codes, formulae, etc., and it is dangerous to forego teaching these important facts.
4. The position of the teacher who encourages discovery is ambiguous, is he to pretend that he doesn't know the answer, or say, I know, but you must find out, and accept the consequences of his actions.
5. When it is necessary to teach a whole class how are a few good students to be prevented from making all the discoveries.
6. Genuine discovery is rare, inside or outside the classroom (pp. 109-111).

Ausubel (1968) warns the educator that "an all-or-none position regarding the use of the discovery method is warranted by neither logic nor evidence (p. 471)," however, learning by discovery does have a place in the repertoire of pedagogic techniques. He considers that:

1. If we are at all concerned with the breadth of his (the student's) knowledge, we cannot possibly expect him to discover everything he is expected to know.
2. Meaningful knowledge is not an exclusive product of creative nonverbal discovery.
3. Discovered generalizations are available for transfer only if and not until after they are discovered.
4. It is impossible to consider the pedagogic feasibility of learning by discovery without taking into account the inordinate time-cost involved.
5. That difficulties are caused by children's subjectivism and by their exaggerated tendency to jump to conclusions to overgeneralize on the basis of limited experience.
6. It is unrealistic to expect that subject-matter content can be acquired incidentally as a by-product of problem-solving or discovery experience.
7. One might reasonably ask how many students have the ability to discover everything they need to know.

8. It cannot be assumed that methods promoting one objective, e.g. problem solving ability, necessarily promote another, such as acquiring a body of knowledge.
9. Overemphasis on developing problem-solving ability would ultimately defeat its own ends. It would leave students with insufficient time in which to learn the content of the discipline.
10. A conflict occurs when students enact the role of a junior scientist. The student must first learn if ever he is to discover, and he cannot learn adequately by pretending to be a scientist.
11. There is no existing or necessary association between a discovery approach to learning and intrinsic motivation.
12. There is no reason to believe that discovery methods are unique or alone in their ability to effect self-confidence, intellectual excitement, and motivation for sustained problem-solving and creative thinking (pp. 476-495).

Ausubel has made a careful study of the claims made for the enhancement of learning by discovery. In his examination of research literature allegedly supportive of this method of learning, he found that valid evidence of this nature was virtually non-existent.

Summary

This chapter described the nature of man as an inquiring animal. Man has used inquiry to solve problems and improve his lot in life since prehistoric time. Eminent scholars recognized the usefulness of inquiry and updated it according to the knowledge of the times in which they lived. A brief history was presented to show the development of inquiry as one of man's tools for interacting with his environment.

The intellectual development of man allowed him to perceive differences in meaning and application of the inquiry method. Use of a variety of terms and techniques under the general banner of discovery-inquiry method created confusion as to the meaning of the term "inquiry

method." A simple explanation was given of its development and it was considered that the most appropriate term to use would be "method of inquiry."

Four recently constructed definitions of inquiry were examined and significant differences were noted. The first two definitions are associated with the role of the teacher and his influence on the learner using inquiry in a learning activity. In the last two definitions a non-instructional context was identified. To inquire in this context involves an expertise usually associated with a scientist at the forefront of knowledge.

The reasons given for the use of inquiry show a concern that the traditional science curriculum fails to present a true picture of the scientific enterprise. Claims made for superior learning activities were also given as reasons for the adoption of the use of inquiry in science instruction.

Two types of inquiry, stable and fluid, were outlined to illustrate important differences. The implementation of one or the other, or both, in a curriculum may affect the general organization of the school's curriculum and their adoption merits serious consideration by the curriculum worker. Models of inquiry activities were used to illustrate the difficulty the teacher encounters when attempting to follow a student's inquiry.

Models of inquiry developed by learning theorists showed different points of view in the method used. On the one hand students were confronted with a problem to be solved, whereas the other method

solved a problem by a sequential development of prerequisite knowledge.

There is no one method or list of activities for an inquiry. The models of the learning theorists and the two types of inquiry illustrate that there is a need for the educator, be he administrator, curriculum worker, or teacher, to be aware of the specific nature of the learning activities being used in the curriculum.

In the next chapter, the discussion will turn to a description of the pedagogical principles to be used when presenting an inquiry.

CHAPTER IV

PEDAGOGICAL PRINCIPLES APPLIED TO INQUIRY METHODS

This chapter examines the various roles of the teacher who implements the methods of inquiry in science instruction. Initially, the important elements which affect the act of learning are outlined prior to a detailed examination of a strategy which can be used when using inquiry as an instructional method. The main areas of the strategy; organization, environment, administration, and nurturant and instructional values are then presented prior to the biological science inquiry model.

The important activities performed by the teacher during an inquiry-centred discourse are then examined. Implicit in each of these activities is the fact that the teacher serves as a model for a good scientific attitude, for this is a controlling influence in the scientific enterprise. However, it is difficult for the teacher to constantly maintain the "attitude model" as the learning requirements for inquiry dictate prerequisite knowledge, most of which is usually obtained by reception learning. A list of specific attitudes which the teacher should try to employ throughout the course are then presented.

Finally, a number of specific learning principles which are applicable to all types of curricula, but which are particularly pertinent to the inquiry-type, will be examined. A summary section concludes the chapter.

Pedagogical procedures required for implementing inquiry-type science curricula should not be conceived as static tenets but as

dynamically interactive among the learner, learning environment, and the curriculum. Of these three the learner is the controlling factor, inasmuch as the financial and human resources expended will be wasted unless learning occurs. Further, regardless of the method used, it should be recognized that students learn not just by doing, but by thinking about what they are doing.

In this respect the educator's first consideration must necessarily be to set the stage for learning to occur. "Inquiry generally aims at the grounding of belief through the use of reason, evidence, inference, and generalization (Massiales & Zevin, 1967, p. 1)." This requires that the curriculum designer structure the subject matter in such a manner that it is amenable to the learners' rationality, yet maintains the integrity of the discipline. According to Schwab, the significance of this problem lies in the educator's knowledge of the discipline. "For to know what structures underlie a given body of knowledge is to know what problems we shall face in imparting this knowledge (Schwab, 1964, p. 13)."

Basically, inquiry-type method is organized around the information-processing capability of the student. This involves "the ways in which people handle stimuli from the environment, organize data, sense problems, generate concepts and solutions to problems, and employ verbal and nonverbal symbols (Joyce & Weil, 1972, p. 9)." Reflective thinking occurs as the student is actively involved integrating and processing this information. Thus whilst most inquiries are designed to teach the

research system of the discipline, secondary effects may occur and thereby influence specific strategies for thinking and creative thinking in the student's environment.

There exist many strategies for implementing inquiry-type science curricula. For the sake of brevity, an outline of a strategy will be presented here.

Organization: The processes of science are used in any order and to varying degrees depending upon the nature of the investigation. Phase 1: The students are required to recognize the existence of a problem. The teacher may use any one of a number of techniques to present the problem. The most popular technique is by a confrontation geared to the students degree of sophistication and interests. During this phase the degree of difficulty and possible methodologies for solving the problem are discussed. The teacher encourages maximum student participation and leads the group in considering all rational suggestions. In the main, discussion centres on areas of difficulty, control of the experiment, generation, collection, organization, and the interpretation of data, and precautions when needed.

Phase 2: The students undertake the investigation in the manner of a researcher.

Phase 3: The teacher and students work together analyzing the strategies used, results obtained, and their consequences. Suggestions for improving the investigation are entertained and areas of concern or difficulty are discussed with the relevant degree of intellectual questioning.

Inquiry Environment:

The teacher's moves are critical. Although the structure of the inquiry is quite high and the social system is largely controlled by the teacher, the intellectual environment is open to all relevant ideas. The teacher and students participate as equals where ideas are concerned A cooperative, rigorous climate is desired (Joyce and Weil, 1972, p. 149, 161).

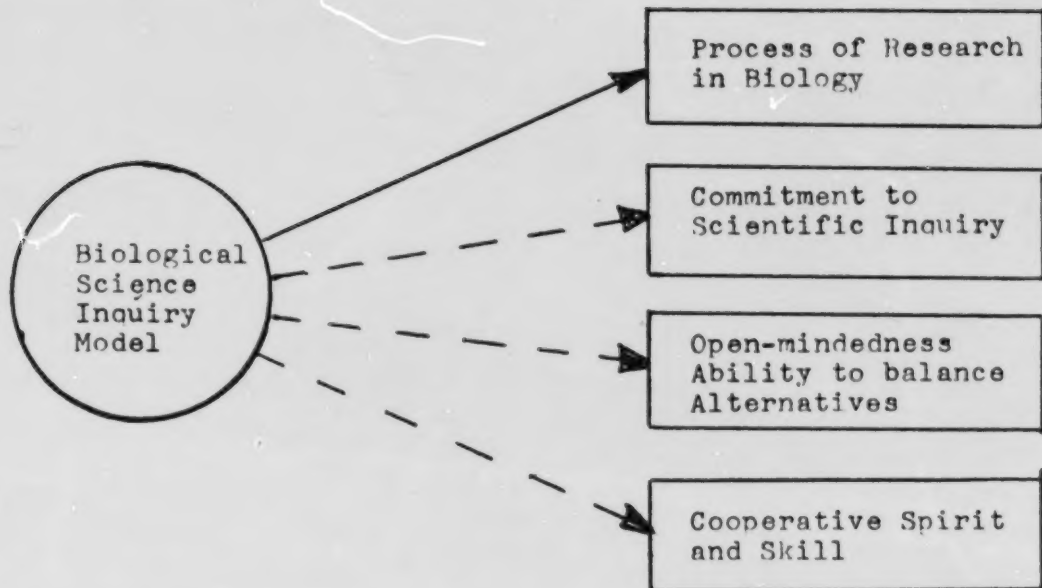
Administration of Inquiry: The teacher's task is to nourish the inquiry and maintain a good level of rigor. He does this by questioning or stressing the various processes of science inherent in the investigation.

Nurturant and Instructional Values: Joyce and Weil (1972) consider "that the Biological Science Inquiry Model (Figure 4) is designed to teach the processes of research biology and to nurture a commitment to scientific inquiry (p. 162)." Through its emphasis on the community of scholars it also nurtures a spirit of cooperation and an ability to work with others in scientific inquiry.

Massialas and Zevin (1967) consider that during the inquiry-centred discourse, the teacher generally performs the following major roles:

1. He plans very carefully the topics, ideas and generalizations that the class may want to explore, and he organizes and times the spacing and sequence of the materials.
2. Often he introduces the initial material that will serve as a springboard for inquiry and discussion. The preparation that goes into the construction of this material can never be over-estimated.
3. He challenges and continuously prods the students to explore and test new alternatives.
4. He insists on the communication of beliefs in public and he asks for the defensibility of statements. He tries to develop the notion that an idea or knowledge-claim is as good as its evidential base presented in the open forum of ideas.
5. He summarizes, recapitulates, and asks for clarification of points made by the students.

Figure 4

The Biological Science Inquiry Model

(from Joyce and Weil, 1972, p. 162)

6. During times of impasse he may raise additional questions regarding the problem at hand. These questions may help the class to see alternative ways of solving a problem.
7. He legitimizes creative expression. In contradistinction to a traditional teacher who frowns upon ideas that are unorthodox, the inquiry-oriented teacher constantly encourages the students "to play their hunches" and to conjecture. He considers this activity to be the core of formal classroom instruction.
8. Finally, he performs several managerial tasks such as recognizing students and making class announcements (pp. 25-26).

The development of a sound, healthy attitude by the student, is important in his investigations. The message imparted by the pedagogical skills of the teacher is considerably influenced by the nature of his attitude. A positive attitude toward scientific inquiry by the teachers is essential since attitudes are learned by the student. In fact, a reflection of the teacher's influence can be seen in education "since teachers tend to teach as they were taught (Peterson, 1969, p. 10)." Thus the teacher who learned science as a rhetoric of conclusions may have to make a deliberate attempt to acquire the spirit of scientific inquiry if students are to gain from their study of science.

The continued use of inquiry-oriented strategies is not always possible. According to Gagné (1963) and Ausubel (1967) certain concepts of knowledge must become established in the learner's cognitive structure before he can understand and integrate new material from an investigation. As a consequence, such "learning needs to be organized as 'reception learning,' that is, in situations where the learner is the receiver of information and ideas (Joyce and Weil, 1972, p. 109)." Under such conditions Socratic questioning may not be possible, particularly when one

considers the time limitations for the course. Thus, it should be recognized that it is difficult to maintain a healthy scientific attitude during every lesson and its usage should be discretely planned by the teacher.

When planning the implementation of scientific attitudes it is useful to consider those listed by Haney (1964); they are

1. curiosity,
2. rationality,
3. suspended judgement,
4. open-mindedness,
5. critical-mindedness,
6. objectivity,
7. honesty, and
8. humility (p. 33).

However, regardless of the values emphasized by the teacher the overriding principle to be remembered is that of consistency, which is a difficult task in this rapidly changing world.

The teacher involved in presenting an inquiry-type curriculum should have an understanding of the associated learning processes. The BSCS considered that an understanding of, and ability to use the pedagogic techniques which bring subject matter and learning processes together is essential for the successful implementation of the course. To this end, BSCS outlined the following specific principles of learning that were used in the development of their course.

1. Learning becomes meaningful when students relate specific facts into conceptual wholes. Learning is discovery of meaning, not merely a change in behavior.
2. Students learn better when they have success and know that they are successful.
3. An atmosphere of respect and acceptance, friendliness, and helpfulness is conducive to learning.
4. Start with skills and understandings the students have and build on these.

5. Learning is more effective when there is active mental participation by the students. Problem solving and situations of interest to the students are likely to encourage active participation.
6. Reinforcement aids learning, particularly when multiple media are used (for example, laboratory, discussions, and readings) and all pertain to the same idea or information.
7. Students learn better when they have some responsibility for determining what they learn (Klinckman, 1970, pp. 81-82).

This chapter has described some pedagogical procedures which are compatible with inquiry-type curricula. It is generally understood in science education literature that inquiry-type teaching involves non-didactic, non-expository techniques. The teacher is required to organize the materials and instruction in such a manner that the students can figure out the concept to be attained for themselves. In effect, the student is involved in a pattern of logical thinking which has been so designed as to maintain the integrity of the discipline, yet aid the learner in his task.

The creation of a favorable learning environment is of the utmost importance. It is generally conceded that an atmosphere generated from important scientific attitudes is conducive to learning. Thus, there is a need for the teacher to deliberately plan to incorporate healthy attitudes into his presentations. Evidently, attitudes play an extremely important role in education, and yet, an attitude is merely a way of thinking.

CHAPTER V

THOUGHT PROCESS ANALYSIS OF SCIENCE CURRICULA

This chapter will focus on determining the thought processes used during an investigation as verbalized in written form, and the possible usefulness such a thought process analysis can be to the educator.

The first section outlines some of the values attached to thinking prior to explaining the pedagogical considerations made in respect to this activity. In the third section the reasons for the use of the thinking chart are given, followed by an analysis of the written report. The thinking chart is referred to throughout the analysis and the thought processes inherent in the investigation are placed in the three main categories according to the chart. The fourth section deals with six specific areas of concern to the curriculum specialist and a detailed discussion is then conducted in each area of concern. Much of the theory related to in the discussion has been stated in previous chapters, however, more theory is referred to in this chapter when deemed appropriate. Reference is constantly made to the student's thinking and the identification of the types of thinking indulged in by the student, of which the educator should be aware. A summary section concludes the chapter.

Values of Thinking

Thinking is a major aim of education. "Of all the methods that are known for solving problems in terms of human needs, human values, and human concerns, thinking represents the one best method available

(Raths, 1967, p. 332)." For "the ability to think is regarded as the distinguishing power that marks man off from lower animals (Dewey, 1933, p. 17)." Thus, there is substantial agreement that an emphasis on thinking is educationally desirable for the benefit of mankind.

The dynamic nature of this ever-changing world requires a constant refining of knowledge which guides man's related activities. For "knowledge does not ensure rational action, but rational action is impossible without the knowledge necessary for reaching logical decisions (Saylor and Alexander, 1966, p. 163)." In this respect,

thinking enables us to direct our activities with foresight and to plan according to ends in view, or purposes of which we are aware. It enables us to act in deliberate and intentional fashion to attain future objects or to come into command of what is now distant and lacking (Dewey, 1973, p. 17).

Man's reflective thinking is thereby converted into intelligent action.

Pedagogical Considerations for Thinking

The emphasis placed on thinking in modern science curricula dictates that the data that count most are cognitive. It is most important therefore, that the teacher know what the student is thinking during the learning activity, for it enables him to evaluate the effectiveness of the curriculum in a particular learning environment. An evaluation of the student's thinking may indicate that a change is necessary in one, or more, of the intended learning outcomes, the sequential development of the topic, or the strategies and techniques used by the teacher. To establish such an insight into the student's mental life requires that the teacher focus his attention on what the student says and writes, in other words, his verbalizing.

Inasmuch as not all students have the opportunity to have their say during a learning activity, it is the written word that is most readily available to the teacher. As one thought leads to another, so a stream of thought processes develop as students formulate concepts and build them into conceptual frameworks as they attempt to solve a problem. The student's laboratory report of such an investigation provides the teacher with an opportunity to analyze the student's thinking. In effect the student's laboratory report reflects the line of reasoning he used to solve a problem. It is evidence of the student's thinking during the learning activity.

It is necessary that the teacher recognize that "thinking is involved whenever a person encounters a situation for which he has no ready-made response (Peel, 1967, p. 68)," that during this state of reflection he is selecting, rejecting, and making inferences, therefore, "thinking is a creative, problem-solving process. It is an attempt to work through an obstacle in order to find the means to achieve an end (Bigge & Hunt, 1968, p. 340).

So construed, reflective thinking differs significantly from deductive reasoning in that it combines both inductive-fact gathering and deductive-logical-processes in such a way as to find, elaborate, and test hypothesis. Thus there is no difference between reflective thinking and scientific processes, broadly defined (p. 345).

The equating of reflective thought process with scientific processes is of considerable aid to the teacher who wishes to analyse the thinking in a student's laboratory report. Dewey (1973) considers that

partial conclusions emerge during the course of reflection. There are temporary stopping places, landings on past thought that are also stations of departure for subsequent thought. We do not reach conclusions at a single jump. At every such landing

stage it is useful to retrace the processes gone through and to state to oneself how much and how little of the material previously thought about really bears on the conclusion reached and how it bears (p. 75).

The temporary stopping places allow for a Thought Process Analysis whereby thought processes can be isolated, identified and related to the mainstream of the student's thoughts in solving the problem. It should be possible for the teacher to appraise and relate that which is learned to the purpose which is governing the encounter.

Thought-Process Analysis of BSCS Investigation 1-4¹⁰⁹

The Academic Reform movement of the 1950's and 60's produced a number of discovery-inquiry curricula. One of these being the Biological Sciences Curriculum Study referred to as BSCS (Biological Science--Molecules to Man, 1968). "The primary objective of BSCS is to teach science as a way of thinking--as a method of seeking answers (Mayer, 1970, p. 1)." An analysis of the student's written work reporting the findings of an investigation in this curriculum should reveal the thought processes (scientific processes) inherent in BSCS. It should also reveal the degree to which the primary objective is achieved and the important relationships among the thought processes.

Bloom's (1956) Taxonomy of Educational Objectives--Cognitive Domain offers an extremely useful format on which the educator can base a thought process analysis. It is the one most educators are familiar with, and the provision of major categories in the taxonomy enables the analyst to recognize the various levels of classification. Further, the explicit organization of the taxonomy clearly delineates the place of each thought process in relation to other processes.

The Thinking Chart developed for the Scottish Integrated Science Syllabus (1969) and presented in Figure 5 will be used for the thought process analysis of the BSCS Investigation 1-4. This is a modified version of Bloom's Taxonomy and is particularly suited to science curricula. The processes in the thinking chart are easily related to those commonly referred to as the processes of science. Curriculum specialists may consider further refining of these processes, however, the primary concern of this analysis is to reveal the processes of science inherent in the activity and in doing so, reflect the universality of how man thinks in the world of science.

A written report for BSCS--Investigation 1-4 will now be examined. The aims of the investigation are followed by a brief statement of the procedures used and the observations are recorded in chart form. The discussion which follows is somewhat detailed and attempts to tie the many observations together into a meaningful whole for which a summary is given. The thinking chart will be referred to step by step as the thought processes in the report are recognized and then recorded on the following pages.

BSCS--Investigation 1 - 4

A Comparison of Living and Nonliving Things Using Phenol Red and Limewater as Indicators

Aims:

1. To differentiate between living and nonliving organisms (or things) using phenol red in a closed system as an indicator.
2. To show whether the substance that causes the change in the above experiment (if one occurs) is also present in human breath as tested by blowing into phenol red.

Figure 5

Thinking Chart*

In Comprehending Knowledge	In Application of Knowledge	In Analysis, Synthesis and Evaluation of Knowledge
Observing	Rearranging	Justifying
Comparing	Relating	Assuming
Classifying	Explaining	Inferring
Summarising	Predicting	Imagining
Interpreting	Estimating	Inventing
Discriminating		Discovering
Illustrating		Generalizing
Extrapolating		Hypothesising
		Testing and Reassessing Hypotheses
		Judging

* Scottish Integrated Science Syllabus, (Scottish Education Department, Edinburgh, Scotland, 1969).

3. To attempt to identify this "substance" (if one exists) by examining the effects of addition of dilute acid, carbonated water, and breath on limewater and phenol red.

Procedure and Observations:

1. Five drops of phenol red were placed into each of seven numbered test tubes. A small brass screw was slid, point first, into each. The specific materials added to each of the test tubes and the results observed are recorded in Figure 5, Section A.
2. Six additional clean test tubes were set up in a rack. Twelve drops of phenol red were added to test tubes 8, 9 and 10. Test tubes 11, 12, and 13 were filled one-fourth full of limewater. The remainder of the materials added to each of these six test tubes and the results obtained are recorded in Section B of Figure 5.

Discussion

The phenol red solution changed color from red to yellow when it had been placed in a test tube containing unboiled yeast-sugar solution, sprouting seeds, or a live grasshopper. It also changed color when blown into. There was no change in color, however, in the control tube (containing nothing except phenol red and a small brass screw), or in the tubes containing the dry seeds, the boiled yeast-sugar solution, or the dead grasshopper. This suggests that something was taking place in the test tubes where the group of actively growing and/or respiring things had been put which was not happening in the tubes which contained nonliving or dormant things. Since none of the organisms was in direct physical contact with the phenol red, it is probable that the substance

Figure 6

Results Obtained From Comparison of Living and Nonliving Things
Using Phenol Red and Limewater as Indicators

	Tube No.	Material added	Indicator change	Time for change
Section A	1	Nothing	No change	-----
	2	Paper towel dipped in yeast-sugar solution	Red → yellow (changed at surface first)	1 min. (approx.)
	3	Paper towel dipped in boiled yeast-sugar solution	No change	-----
	4	5 dry bean seeds	No change	-----
	5	5 sprouting bean seeds	Gradual change from red to yellow	about 10 min.
	6	Live grass-hopper	Gradual change from red to yellow	about 10 min.
	7	Dead grass-hopper	No change	-----
Section B	8	5 drops dilute sulphuric acid	Red → yellow	Instantaneous
	9	10 drops carbonated water	Red → yellow	Instantaneous
	10	Breath blown through straw into phenol red	Red → orange	10 sec.
	11	15 drops acid	No change	-----
	12	Carbonated water (5 drops) (15 drops more)	Clear → cloudy Cloudy → clear	----- -----
	13	Breath blown through straw into limewater	Clear → cloudy Cloudy → clear	5 sec. 15 sec.

(from Searles, 1973, pp. 8-13)

causing the color change is something which is given off by the organism, probably in the respiratory process, as suggested by the colour change that occurs when the phenol red is blown into.

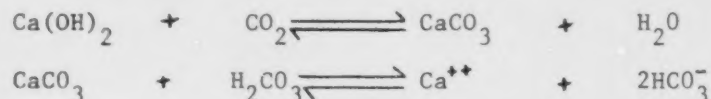
In an attempt to establish the chemical nature of this substance, dilute sulphuric acid and carbonated water (water to which carbon dioxide gas has been added under pressure) were tested for their effect on phenol red. Both substances led to a color change, suggesting that the substance involved is either an acid or, more likely, something in the carbonated water. It is conceivable that the carbon dioxide gas could react with the water to form carbonic acid, and that the acid is really the cause of the change in colour of the indicator.

Further attempts to establish the nature of this substance, which is apparently given off by living organisms, were made by comparing the effects of blowing into limewater (clear solution turned cloudy, then cleared again with additional blowing) with the effects of adding acid or carbonated water. No change was observed in the case of the acid, while the addition of carbonated water led to the limewater's becoming cloudy, followed by clearing with the addition of more carbonated water. This pattern was similar to that of blowing into the limewater, implying that it is most probably carbon dioxide that is being given off by living organisms and that causes the change in the phenol red.

The result that was obtained--the limewater becoming cloudy, followed by clearing with the addition of more carbon dioxide--can be explained by the formation of a white precipitate, calcium carbonate, which dissolves in the presence of the bicarbonate ion. The bicarbonate

ion would have been formed with the addition of more carbon dioxide gas.

These reactions are represented by the following equations:



Summary:

1. A substance that causes a change in the color of phenol red solution is given off by living organisms but not (or in minute quantities) by nonliving or dormant ones.
2. This substance is present in the breath of human beings.
3. From a comparison of the results obtained upon adding dilute acid or carbonated water to phenol red and limewater with those obtained using living organisms, it is suggested that the substance given off is carbon dioxide.

Analysis of a Laboratory Report

In Comprehending Knowledge:

Observing	-	the color change of phenol red.
Comparing	-	comparison is made with a control.
Classifying	-	test tube materials were classified into living or nonliving things.
Summarizing	-	the table is a summary of observations during the experiment.
Interpreting	-	interpretation of results is given in the statement, "This suggests that something was taking place in the test tubes where the group of actively growing and/or respiring things had been put, and that it was not happening in the tubes which contained nonliving or dormant things."
Discriminating	-	limewater is used to discriminate between color change of phenol red caused by an acid and that caused by carbonated water.

- Illustrating - an equation illustrates a chemical reaction.
- Extrapolating - the idea that the group of actively growing things in the test tubes produces carbon dioxide was extended to cover all living things.

In Application of Knowledge:

- Rearranging - rearrangement of conclusions arrived at in the discussion takes place in the final summary.
- Relating - the observation made when carbonated water is added to limewater is related to those made while blowing into the limewater: "This pattern was similar to that of blowing into limewater."
- Explaining - an explanation of the results obtained when limewater was blown into is given in the final paragraph of the discussion: "The result which was obtained--that of the limewater's becoming cloudy, followed by clearing with the addition of more carbon dioxide--can be explained by the formation of a white precipitate, etc."
- Predicing - a reaction is predicted between carbon dioxide and water: "It is conceivable that the carbon dioxide gas could react with the water to form carbonic acid."
- Estimating - time for color change to occur is estimated.

In Analysis, Synthesis, and Evaluation of Knowledge:

- Justifying - that a color change occurs when phenol red is blown into the test tube justifies the assumption that the color change is caused by something given off in the respiratory process.
- Assuming - assumption is made that the color change is caused by something given off in the respiratory process: "It is probable that the substance causing the color change is something which is given off by the organism, probably in the respiratory process."

- Inferring - it is concluded that carbon dioxide causes the change in the phenol red: "This pattern was similar to that of blowing into limewater, implying that it is most probably carbon dioxide which is being given off by living organisms and which causes the change in the phenol red."
- Imagining - this takes place when forming any hypothesis: "It is probable that the substance causing the color change is something which is given off by the organism, probably in the respiratory process."
- Inventing - an experimental method is established to identify the substance causing the color change.
- Discovering - takes place throughout the experiment. It is discovered that the pattern of the limewater and carbonated water is similar to that of blowing into limewater.
- Generalizing - dilute sulphuric acid is tested with phenol red and the result stated for acids in general.
- Hypothesising - it is suggested that the substance causing the color change would be an acid or something in the carbonated water.
- Testing and
Reassessing
Hypotheses - acid and carbonated water are tested with limewater and then the pattern is compared to that of blowing into limewater. This leads to the reassessment of the hypothesis that the color change could be caused by an acid or something in carbonated water.
- Judging - all the observations are examined and it is concluded that the substance is carbon dioxide.

Discussion of the Analysis

The purpose of the thought process analysis is to determine the pattern of thoughts generated by the student when undertaking an inquiry-type investigation, in this case BSCS 1-4. In this respect, the following areas will be examined as they related to the curriculum:

1. The sequence of thinking,
2. The manner in which the student processes information,
3. The structural organization of science as inquiry,
4. The specific types of thinking used by the student,
5. Instructional effects,
6. Aids to the curriculum worker.

1. Sequence of Thinking: As the investigation proceeded the sequential development of thought processes followed a hierarchical pattern. Initially, the student made simple observations which were then analyzed according to various attributes. These observations became increasingly complex as varying degrees of importance were given to the observed attributes. By contrasting and comparing different sets of observed facts categorization occurred in a logical sequential manner. This is in line with Taba's (1962) reasoning that careful planning of sequences in the development of thought is necessary. However, a sequential development is possible only if there is a clear enough understanding of both the specific behaviors that comprise thinking and of the necessary steps in their development.

It can be seen from the recorded observations that the student was able to understand the knowledge to the extent that interpretations, discriminations, and extrapolation could be made. Thoughts of a more

complex nature were then generated in the application, analysis, synthesis, and evaluation of knowledge.

If thinking can be learned only by doing, then the primary objective of the Biological Sciences Curriculum Study was achieved during this investigation.

2. The Student's Processing of Information: BSCS Investigation 1-4 is organized for the attainment of the concept that living things give off carbon dioxide. It was arranged in such a manner that the concept was embedded in the content material. The curriculum designer organized the activities, and the materials, so that the concept was identified not merely from the recognition of a single attribute or inference, but from many attributes in a particular relationship to one another. In this respect, the reaction of an indicator to living plant and animal organisms is related to those inorganic effects on the same indicator. Furthermore, the investigation was a practical illustration of the strategies which people use to learn a concept.

The student involved in this inquiry processed the information derived from specific strategies for thinking. It was necessary for the student to know what features (attributes) of the environment are relevant for grouping materials into categories. This then, was a prerequisite, for "unless there has been experience in some degree analogous, which may be represented in imagination, confusion remains mere confusion (Dewey, 1910, pp. 12-13)." However, it can be seen from the student's thought processes that the plan for the investigation is

based on analogous experience and prior knowledge of these concepts associated with the indicator change. The student was now able to classify the observed reactions and then submit them to the process of scientific investigation in order to solve the problem.

During the problem solving activity the student was engaged in reflective thinking. Initially, the student was confronted with a situation in which a problem existed, the method for solving it was unknown, yet it could be found. In effect, the situation was challenging, but not baffling. There followed a period of reflective thinking--inquiry--during which time the student pondered over the confused, indeterminate situation, and transferred it into a unified and determinate one. Further, a hypothesis was formulated, reassessed, judged, and then stated in terms referring directly to the original problem as finally defined. Note also, that the student suspended judgement, even in the face of seeming certainty, until further searching inquiry had been conducted. It is also interesting to note that implicit in this inquiry, and revealed by the analysis, is the fact that "man has an urge to know, an urge to base thinking and action on knowledge which he knows to be reliable (Dewey, 1910, p. 9)," although that it may only be momentary.

The students formulation of clear conceptions formed by first-hand experience is indicative of well organized, systematic thinking which is considered to be an acquired ability. It cannot be claimed that Investigation 1-4 was responsible for the student acquiring this ability, yet as an exercise in reflective thinking it undoubtedly promotes such an

ability. Thus, in reference to training students to think, 1-4 provides a useful vehicle; the analysis reveals the depth and the degree of the student's thinking in the pursuit of meaning.

A summation of the student processing the information reveals the organization of data collected from the initial observation in tabular form. Interesting comparisons of sections A and B led to the recognition of a pattern, similar to that of blowing into the limewater, which eventually led to a summary of conclusions. The isolated thought processes can be related to Dewey's (1910) temporary stopping places (p. 75) where reflective thoughts provide for the departure of subsequent thought until the attainment of the concept occurs.

3. Science as Inquiry: The laboratory work in 1-4 was arranged to induce the student to investigate the problem rather than receive information as a rhetoric of conclusions, either verbally, or from a text. The student's thinking was a reflection of the structural investigation that was so organized as to enable the student to follow, and participate in reasoning associated with a researcher investigating a problem in biology. Initially, the analysis revealed the student observing and collecting data which became knowledge as it was interpreted. The search for data proceeded on the basis of concepts and assumptions which changed as the amount of relevant knowledge grew, and this changed too, with the testing and reassessing of the hypothesis. Thus, the dynamic nature of science was stressed as knowledge was gained. In effect, the investigation was a practical illustration of the definition of science, as well as that of scientific inquiry in which the student was involved.

4. Types of Thinking in 1-4: Reflective thinking, alias critical thinking, is identified with problem solving when the cognitive abilities of the mind, such as observing, classifying, and comparing are put to use. During the investigation, after many careful observations have been made, a hypothesis was formulated which is tested prior to the final conclusions (summary). The scientific processes present in the report are those engaged in during problem-solving activities. The association of these ideas and the tendency to revise ideas as the investigation proceeded is divergent thinking. However, inasmuch as the student was striving for and eventually achieved a final conclusion, convergent thinking was present, too.

5. Instructional Effects: The pedagogical techniques used in the presentation of 1-4 can be seen in the thought process analysis. As the students progressed through the inquiry a concept was being logically and sequentially built. It was necessarily progressive as each new step along the way required the recognition of, and understanding of concepts which were to be the underpinning for the attainment of the final concept. Furthermore, the rearrangement of conclusions which occurred during the student's application of knowledge indicated an exploration of the ways of improving the categorization process in order to achieve a state of equilibrium. In this respect it should be noted that throughout the whole inquiry specific concepts were being taught as the student processed the subject matter.

6. Aids to the Curriculum Worker: The thought process analysis is most useful in pointing out that "the curriculum consists of two different things; the content and the learning experiences of the mental operations that students employ in learning content (Taba, 1962, p. 265)."

The processes of science outlined by the analysis may be used as a criterion on which to base an evaluation of the effectiveness of learning. Measurements based on these specific thought processes should maintain the required standards of validity inherent in a true evaluation.

The term evaluation is used as an all-encompassing one in curriculum. There is a need for the curriculum worker to examine every facet to determine whether they are in harmony with the whole curriculum. Basically, a thought process is a facet of the curriculum which may be evaluated for its own specific dimensions, or its effects upon the whole. Both of these aspects will be implicit in the evidence upon which the curriculum worker evaluates the curriculum.

The objective based on the molecular level was achieved during this investigation. The color change the phenol red was explained according to the atomic-molecular theory, as in fact, were the other chemical reactions, the symbols were used in the form of a chemical equation to make the point. The thinking involved in this development is known as reflective thinking, and it is present in all problem solving. During this investigation an "indeterminate situation was transformed into a unified and determinate one (Burton, et al., 1960, p. 28)." The length of the period of inquiry may be crucial one for the learner. If too long, the learner may lack the stamina or ability required to maintain the necessary level of intellectual activity; if too short, it may become trivial. However, it could well be that the relative strength of a discrepant event, used to generate motivation, may prove to be the controlling fact in the length of the student's concentration.

"High-level intellectual activity does not usually occur unless the student's attitude toward the pursuit induces him to release the energy needed to complete the activity (Anderson and Koutnick, 1972, pp. 14-15). If one considers that the thought processes used at this grade-level during the investigation were at a high-level, then there is need for serious consideration of the implementation of Haney's (1964) development of scientific attitudes (p. 33).

A recognition of the sequence of thinking in this investigation is extremely important, for "organized, systematic thinking, is clearly an acquired ability (Burton, et al., 1960, p. 15)." In this respect the curriculum will be influenced by the extent to which the student is capable of engaging in this activity. The curriculum worker may state that this acquired ability is a prerequisite, or, organize the course activities sequentially for the attainment of this ability.

The first unifying theme in the BSCS curriculum dealt with change of living things through time. This requires an initial understanding of what is meant by the term, living. Knowledge of inorganic chemical reactions was used to determine the difference between living and non-living things. A series of the student's observations revealed the reasoning as the discrepant event was overcome. The investigation was so arranged "that growth in scientific thinking abilities will occur through those experiences which permit the student to be a scientist (Burton, et al., 1960, p. 418)."

In this respect, the principles of rational thinking emerge from the learning experience.

"Pertinent research indicates that we can teach students to think effectively (Burton, et al., 1960, p. vi)." In fact, the primary objective of BSCS, to teach science as a way of thinking, is in line with these findings. As the analysis reveals the extent to which thinking has occurred, the educator is provided with a list of specific opportunities within the curriculum which afford the student practice in effective thought. Also, the fact that reflective thinking is equated with scientific thinking allows the curriculum worker to determine whether the student undertook the investigation in the manner of a scientist.

A thought process analysis provides a clearer picture of the student's learning activities which may be referred to learning theories for substantiation. The student's thought processes during the classification activity can be associated with Bruner's theory of categorization (LeFrancois, 1972, pp. 206-222). Reference to this theory by the educator may confirm the usefulness of his learning activities, or indicate where improvement is possible. Thoughts associated with the indicative change for living and non-living materials could very well be considered as one of Suchman's discrepant events which may prove to be a hurdle for some students striving for concept attainment. Further, when one considers that knowledge associated with one activity was a prerequisite for a further progressive step, then Gagné's (1963) requirements for learning occurred throughout the investigation. Good theories are those which

describe, explain, and allow predictions to be made and in this manner substantiate curriculum development.

Summary

The aims of education are selected to meet the needs of the learner, and the school's curriculum should be designed accordingly. An analysis of the student's thinking reflects the manner in which he processes information, therefore, it can be a valuable guide to the curriculum committee charged with the responsibility of adopting a curriculum. This is also true for curriculum workers who are responsible for constructing a curriculum in harmony with the aims and objectives of the school system. In effect, each facet of the curriculum extracted from the student's thinking is a guide for the selection of the many components which make up the curriculum.

One aspect of the curriculum not reflected in the thought process analysis is the associated skills. In my experience, this is a vital area of concern in an experimental investigation, and many inquiry-type learning experiences have failed for the lack of a clear-cut explanation of a required skill.

The organization of curriculum content should reflect the needs of the students whilst maintaining the integrity of the discipline. An analysis aids in the selection and sequencing of the components of the curriculum by reflecting the manner and sequence in which the student processes information. This allows the curriculum worker to construct an investigation in a like manner.

The associated instructional objectives may likewise be constructed from a thought process analysis. Furthermore, it should also guide the teacher in the selection of an instructional strategy for implementing the learning experience. The sequencing of learning activities, from the known to the unknown, from the simple to the complex, and from the complex to the abstract, may lean heavily on learning theories. However, inasmuch as learning theories related to the general, and the teacher is most interested in the specifics in his own classroom, a thought process analysis of his student's work may provide a better guide for his sequencing of learning activities.

Evaluation which encompasses the whole curriculum can be established by recognizing that each thought revealed by the analysis provides material which can be subjected to measurement. The analysis may also suggest the type of instrument and procedures to be used in the evaluation.

It is generally conceded that there is a gap at both ends of curriculum development. By using a thought process analysis it may be possible to close that gap.

CHAPTER VII

SUMMARY AND RECOMMENDATIONS

The purpose of this curriculum monograph has been to answer the question "What is the usefulness of a thought-process analysis to the educator who is required to teach, design, or adopt, inquiry-type science curricula? In doing so, several other related questions have been raised: (1) What is meant by the inquiry-type method? (2) Can pedagogical techniques influence inquiry-type curricula? and (3) Why thinking occupies such an important role in inquiry?

What is meant by the inquiry-type method?

It is now generally recognized that inquiry is the process of investigating a problem in search of information or knowledge, and that there are many methods of inquiry at varying levels of intellectual ability and complexity.

Can pedagogical techniques influence inquiry-type curricula?

Based on the diagnosis of student needs, learning environment, and the curriculum, an inquiry may be structured so that the student is able to formulate the concept to be attained for himself. In this manner the student uses his powers of reasoning, discrimination, inference, and generalization to achieve the concept. The teacher's sequencing of the learning activities must be amenable to the learners' rationality. In this respect, the teacher prescribes the educational experience for the student and organizes it accordingly. Thus, the needs of the student are met, the integrity of the discipline maintained, and the student gains

knowledge in a manner common to the nature of the discipline, albeit that the learning activity was highly structured by the teacher.

Why does thinking occupy such an important role in inquiry?

The roots of the problem discussed in this monograph lie deep in man's ability to think, for it is by constructive thought that man is able to solve problems. This productive enterprise emanates from the student's ability to formulate thoughts relative to the problem, specifically to an increased understanding, and an application of that understanding. In this respect, the teacher's understanding of the student's thoughts and thought patterns enables him to design relevant learning experiences within the curriculum. Furthermore, knowledge of the student's thinking can be applied to the various components which make up the curriculum.

A hypothesis regarding the question of the usefulness of a thought process analysis to the educator can now be formulated. Based on the diagnosis of the analysis, the teacher may revise the curriculum within a classroom to accommodate the needs of the students by

1. presenting discrepant events that will motivate the learner to become actively involved in a learning experience from which he will obtain satisfaction,
2. guiding the student conducting an investigation and supplying the appropriate materials,
3. providing sequential practice so that it becomes part of the student's repertoire,
4. setting standards that are amenable to the discipline and within the rational experience of the student,

5. an exhibition throughout the curriculum of those attitudes implicitly in the nature of science, and
6. implementing, implicitly or explicitly, the goals of science education.

In this respect, the curriculum designer will create a curriculum relative to these needs and the inquiry-type science curricula. And, inasmuch as a thought process analysis provides the specifics of the student's thinking in the curriculum, it provides a useful guide to the educator.

Some Further Thoughts

The major findings presented in this report were related to a curriculum whose objective was to present biology as a way of thinking. Many questions may now be raised as to the applicability of a thought process analysis to other curricula. Will it help to establish commonalities existing in different courses and thereby aid in decision making? For example, course A is preferred over course B at the grade nine level, however, course B is implemented because it provides better sequencing of content and processes for course X given in grade ten.

To what extent can a thought process analysis determine the worth of a learning experience or the type of question to be used in evaluation? Can a thought process analysis aid in the adoption of a nationally or publisher-designed curriculum? In planning learning experiences in a curriculum? If so, how can it provide such aid? Is there a progression of thought process skills? Can these skills be sequenced and, if so, should they be? Can a curriculum be designed with thought processes as a key factor? Do teachers "specialize" in one

thought process or another? Do teachers have a thought process style? Many questions remain to be answered as to the possible value of the use of a thought process analysis by the educator, for thinking still remains a major aim of education, and its role in the curriculum must be understood if standards of validity are to exist in education.

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APPENDIX A

NSTA POSITION STATEMENT ON
SCHOOL SCIENCE EDUCATION
FOR THE 70s

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NSTA
POSITION STATEMENT ON

School Science Education for the 70s

Prepared by the NSTA Committee on
Curriculum Studies: K-12 and presented to the NSTA Board of
Directors at its annual meeting in July 1971.

INTRODUCTION

In 1962 the National Science Teachers Association issued its first position statement on curriculum development in science. In view of the many changes that have occurred in the past decade and in recognition of the belief that curriculum development should be a continuing process, the NSTA Committee on Curriculum Studies: K-12 has reexamined the 1962 views on the science curriculum and produced the revised position statement comprising this document.

In our rapidly changing society, curriculum development should be a continuous process, changing as the needs of society change. The National Science Teachers Association has, therefore, again examined its beliefs about the science curriculum in view of the developments of the past decade and those anticipated during the next decade. The officers, the board of directors, committees, and the members have considered these changes carefully in the formulation of this Position Statement.

In the fall of 1969 the NSTA Committee on Curriculum Studies: K-12 mailed a questionnaire to about 125 science educators in an attempt to survey their views on the content and emphases of the new Position Statement. Their generous response to the questionnaire and a thorough review of the science education literature provided background information

used in developing this statement. A series of drafts of the Position Statement were presented to the NSTA membership during regional or national conventions. The first draft was presented during an open forum at the 1970 NSTA Convention in Cincinnati, Ohio. The second draft was presented to several regional conferences during the fall of 1970. The third draft was presented during an open forum at the 1971 NSTA Convention in Washington, D. C. Feedback from NSTA members as a result of these meetings was considered carefully in developing the final draft of the Position Statement which was approved by the Board of Directors in July 1971.

The Position Statement is published to offer guidance to all those who are interested in the Association's beliefs on curriculum development in science. The positions emphasized in this statement can serve as a guide to

those individuals engaged in modifying, implementing, or developing new programs in science. Because the importance of this Position Statement lies in its usefulness in stimulating thought and discussion concerning curricular decisions, the addendum to the statement deals with recommended action by NSTA to interpret and disseminate the ideas presented in the statement.

The committee urges all members to consider the ideas presented in this Position Statement and to make suggestions for its clarification and refinement. Suggestions should be communicated directly to NSTA Headquarters, 1201 Sixteenth Street, N.W., Washington, D.C. 20036.

*Glenn D. Berkheimer, Chairman
NSTA Committee on Curriculum
Studies: K-12*

GENERAL GOALS OF SCIENCE EDUCATION

The major goal of science education is to develop scientifically literate and personally concerned individuals with a high competence for rational thought and action. This choice of goals is based on the belief that achieving scientific literacy involves the development of attitudes, process skills, and concepts, necessary to meet the more general goals of all education, such as:

- learning how to learn, how to attack new problems, how to acquire new knowledge
- using rational processes
- building competence in basic skills
- developing intellectual and vocational competence
- exploring values in new experiences

- understanding concepts and generalizations
- learning to live harmoniously within the biosphere

Above all, the school must develop in the individual an ability to learn under his own initiative and an abiding interest in doing so. [1]

The goal of science education should be to develop scientifically literate citizens with the necessary intellectual resources, values, attitudes, and inquiry skills to promote the development of man as a rational human being.

THE SCIENTIFICALLY LITERATE PERSON

Many traits may be typical of a scientifically literate person.

Each of these characteristics should be thought of as describing a continuum along which the individual may progress.

Likewise, the combined characteristics may be viewed as a larger continuum. Progress in an individual's science education should be equated with progress along this continuum.

The scientifically literate person

- uses science concepts, process skills, and values in making everyday decisions as he interacts with other people and with his environment
- understands that the generation of scientific knowledge depends upon the inquiry process and upon conceptual theories
- distinguishes between scientific evidence and personal opinion

- identifies the relationship between facts and theory
- recognizes the limitations as well as the usefulness of science and technology in advancing human welfare
- understands the interrelationships between science, technology, and other facets of society, including social and economic development
- recognizes the human origin of science and understands that scientific knowledge is tentative, subject to change as evidence accumulates
- has sufficient knowledge and experience so that he can appreciate the scientific work being carried out by others
- has a richer and more exciting view of the world as a result of his science education
- has adopted values similar to those that underlie science so that he can use and enjoy science for its intellectual stimulation, its elegance of explanation, and its excitement of inquiry
- continues to inquire and increase his scientific knowledge throughout his life

To promote scientific literacy, science curricula must contain a balanced consideration among conceptual schemes, science concepts, and science processes including rational thought processes, the social aspects of science and technology, and values deriving from science. Scientifically literate persons will use the achievements of science and technology for the benefit of mankind. These goals

must be achievable, at least in part, during the immediate school experience.

Science, because it is a human undertaking, cannot be value-free. Emphases on values and on the social aspects of science and technology must be integral parts of any science curriculum.

The following values underlie science:

- longing to know and understand
- questioning of all things
- search for data and their meaning
- demand for verification
- respect for logic
- consideration of premises
- consideration of consequences [2]

The major educational challenge of the next decade is to develop learning environments to prepare young people to cope with a society characterized by rapid change. To cope with and attempt to solve problems in a rapidly changing society, young people will need to develop science process skills and associated values to a greater extent than have similar groups in the past. All teachers, and especially science teachers, are challenged to educate young people to expect, to promote, and to direct societal change.

Awareness of the social aspects of science includes

- perception of the cultural conditions within which science thrives
- recognition of the need to view the scientific enterprise within broad perspectives of culture, society, and history
- expectation that social and economic innovations may be necessary to improve man's condition
- appreciation of the universality of scientific endeavors [3]

CURRICULUM DEVELOPMENT, REVISION, AND IMPLEMENTATION

Although the development of scientifically literate individuals is considered to be the central purpose of science education, a single or "best way" of pursuing this goal cannot be specified. The diverse nature of schools, students, and teachers necessitates a variety of programs and approaches.

To develop a scientifically literate citizenry, the NSTA Committee on Curriculum Studies: K-12 recommends that:

- every individual have an opportunity for many science experiences, every year
- every science teacher be supplied with adequate science facilities, equipment, and supplies, and time to utilize these [4]
- science be taught as a unified discipline, integrated and/or coordinated with other disciplines, such as mathematics, social science, economics, political science, and others
- increasing emphasis be placed on science processes, conceptual schemes, and values; and less emphasis on factual information
- direct experiences with the natural world or in the laboratory should comprise the major portion of the science program
- textbooks should facilitate inquiry, rather than being written to replace laboratory experiences. The use of recorded material (other media as well as printed material) should be integral

parts of and dependent upon laboratory experiences:

- science education programs include environmental education that interrelates natural phenomena, environmental influences, science, technology, social implications of science and technology, and economic considerations
- opportunities for the professional growth of teachers be considered an integral part of science education programs so that teachers' own deeper insights can be brought to bear on the science programs designed for scientific literacy [5]

The achievement of scientific literacy should be the basis for setting objectives; for selecting content, learning experiences, and methodology; and for developing a system of evaluation.

The following groups of questions may be used in guiding the development or revision of a science curriculum and in assessing a science program designed to promote the development of scientific literacy. In posing these particular questions, the Association is taking the position that these questions emphasize important areas of concern for the development, revision, or implementation of curriculum.

APPROPRIATENESS OF OBJECTIVES

To verify the appropriateness and validity of objectives, in their original selection and in periodic assessment later, questions such as the following should be asked:

- Is the objective consistent with the nature of science?

- Is the objective consistent with the nature of the learner?
- In what respects does the objective have relevance for students?
- Will what is proposed for learning contribute to a student's progress toward the achievement of scientific literacy?
- Have the proposed objectives been examined for authenticity and importance by scholars in science and in science education?
- for suitability as educational tasks by school personnel?
- for desirability and potential usefulness by thoughtful lay citizens?
- for potential interest by students?

CONTENT, LEARNING EXPERIENCES, AND METHODOLOGY

Selection of content, learning experiences, and methodology used in the science program should be made by the individuals involved in each school system. The following questions are posed as guides to help school personnel develop science programs and/or modify available materials and programs to meet local needs.

- Does the program contribute to the development of a student's concept of himself as an adequate person?
- Does the program foster student liking for science in general and for independent investigation in particular?

- Is the total science program student-centered?
sequential, K-12
structured to enable students to pursue topics of their choice in depth?
structured to enable students to explore a great variety of topics?
- Is there a sound rationale for the organization of content and learning experiences?
Does the organization provide for flexibility consistent with the nature of the students for whom it is intended?
Is the organization consistent with the structure of science?
- Does the program foster student perceptions and relationships among the sciences and other school subjects, such as social studies and mathematics?
- Do the media chosen enable students to pursue science in various ways? (Media should not be chosen as ends in themselves.)
- Does the individual have an opportunity for investigative activities involving open inquiry?
first-hand experience with physical and living things?
a variety of settings (laboratory, field work, library, etc.)?
- Does the program provide opportunities for students to work both on an individual basis and as members of various-size groups?
- Does the program contain provisions for students to explore individual interests?
- Does the program not overwhelm the student with masses of knowledge?

EVALUATION

The Association reaffirms its belief that evaluation should be closely tied to the stated objectives of a given curriculum. Objectives should be stated independently of the problem of evaluation, and methods should then be sought to test the attainment of these objectives. Where the evaluation of valid, clearly stated objectives turns out to be difficult, this should be interpreted as a weakness in our techniques of evaluation, not necessarily as a weakness in the objectives. This may be especially true in the affective domain, in the development of an individual's self-image, and in the determination of his values.

Questions such as the following are important when evaluation activities and instruments are being designed or selected.

- Does the evaluation system
 - reflect the same relative emphasis among conceptual schemes, process skills, social aspects of science, and values as do the stated objectives?
 - contain an ongoing program of student self-evaluation based on criterion performances and providing feedback to the students?
 - go beyond paper-and-pencil tests so that a variety of means are used for collecting data about student achievement?
 - provide a basis for judging the effectiveness of instruction, in revising programs, and in improving feedback to the students?
 - include instruments and techniques that measure what they purport to measure?

- acknowledge the concept of student and teacher progress along a continuum toward the goal of scientific literacy and provide a means for each to assess his position on the continuum?
- does the evaluation system attempt to measure the higher thought processes and the affective domain, as well as recall, association, and other common areas?

Science education for the 70's, therefore, has as its goal a deepening and expanding concept of man in the universe, with a parallel development of attitudes and values that, together with similar literacy in other areas of experience, will determine the way individuals and communities of individuals make use of knowledge, perceive consequences of their actions, and balance freedom and responsibility within their own lives and in the structure of society.

THE ROLE OF NSTA IN CURRICULUM DEVELOPMENT

RECOMMENDED ACTION

The National Science Teachers Association considers the development of a science program for a school system to be the responsibility of the science personnel of that system. However, the Association also recognizes a responsibility to assist the practitioner of science education in translating the ideas contained in the NSTA Position Statement on School Science Education for the 70's into viable science programs. Therefore, the NSTA Committee on Curriculum Studies: K-12

recommends that the Association involve itself in curriculum development and makes the following specific recommendations to the Association and its sections and affiliated groups for action in regard to curriculum development.

INTERPRETATION AND DISSEMINATION

The ideas set forth in the Position Statement must be translated into a form that has utility for curriculum specialists and for classroom teachers. Therefore, NSTA should undertake actions such as the following:

- A publication on science curriculum development that illustrates how broad goals can be translated into instructional programs.
- Development of curriculum modules, on a sample or pilot basis, that exemplify the approaches suggested above for content and process and that demonstrate techniques to *facilitate flexibility and individualization* in program organization.
- Inclusion of workshops on curriculum development and teaching style at meetings of the Association
- Further identification of criteria for making curriculum decisions that are based on the goals previously described
- Continuing review of curricula and curriculum development processes
- Action as a clearinghouse, through its various journals, for ideas on science curriculum development, design, and production

SUPPORTIVE ACTION

NSTA should catalyze and support the efforts of local, state, and national groups through activities such as:

- Establishment of a consultant bureau of NSTA members especially knowledgeable in the area of science curriculum as a clearinghouse for requests for curriculum assistance
- Assistance to groups that wish to experiment with differing patterns of organization, such as unified science, integrated science-humanities courses, problem-centered courses, and efforts to individualize instruction
- Encouragement of programs and courses for teachers that implement the recommendations of this Position Statement

DATA COLLECTION

NSTA should collect data concerning science instruction in our schools and colleges and disseminate this information. This might include:

- Research, done by the Association or by cooperating groups, to determine how various kinds of curricula function in differing educational environments
- Publications and meetings to serve as forums for the discussion of all elements of curriculum development and implementation

- Forums at national and regional meetings of the profession
- Centers for curriculum materials and instructional demonstrations, at meetings of the Association
- Articles in appropriate professional journals that reach all science teachers

References

1. The statements are adapted from *Schools for the 60's*, a product of the NEA Project for Instruction. Although it was produced ten years ago it is still a valid, viable statement of goals.
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4. See also *Conditions for Good Science Teaching*. Recommendations of the Commission on Professional Standards and Practices of the National Science Teachers Association. The Association, Washington, D.C. 1970.
5. See also *Annual Self-Inventory for Science Teachers in Secondary Schools*. Commission on Professional Standards and Practices. National Science Teachers Association, Washington, D.C. 1970.

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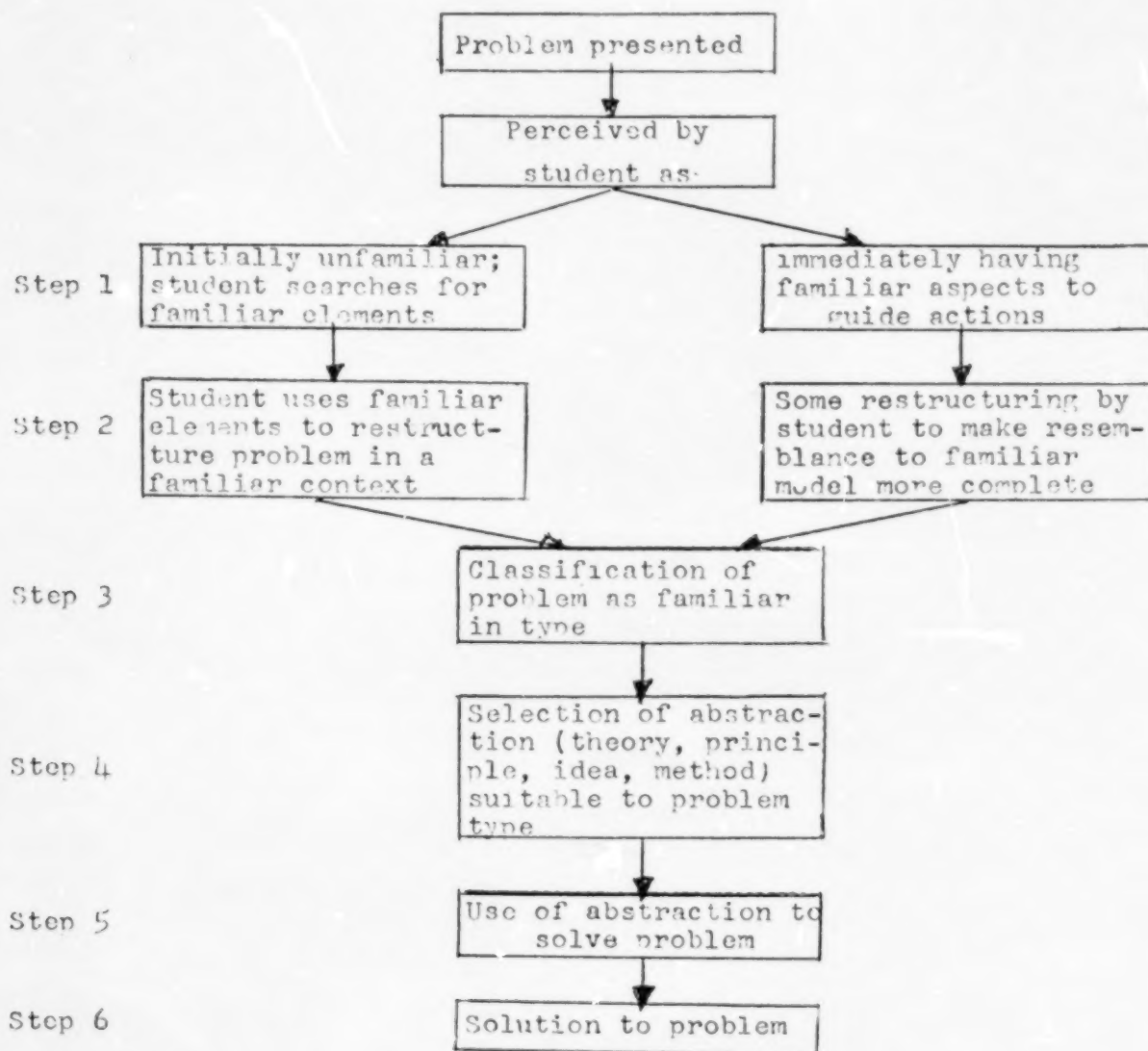
Lucy L. Smith, Public Schools, Atlanta, Georgia

Richard J. Merrill, President NSTA, *ex officio*

Robert H. Carleton, Executive Secretary, NSTA, *ex officio*

APPENDIX B

Bloom's Model of Problem-Solving



(Bloom, et al. Taxonomy of Educational Objectives: The Classification of Educational Goals -- Handbook II, p. 121.)